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Research Article

Artificial Models for Determining Antenna Parameters for a Resonant Frequency

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Abstract

In this paper, two models are developed based on artificial intelligence which can be used to estimate the length, width and position of the radiating element which are the design parameters of square monopole antenna required to make it operate in a particular frequency band of 4.5 GHz and 8.9 GHz. All the antennas designed using these models gives a wideband of 4.5GHz – 5 GHz. One of the two models were developed using Artificial neural network(ANN) and the other model was developed using a hybrid technique of ANN and Fuzzy logic named as Adaptive neuro fuzzy inference system(ANFIS) .The results given by the prepared models are compared with the results of IE3D software which are accurate enough to be used for designing square monopole antenna . The hybrid model called ANFIS combines both the training and optimization techniques due to which it is giving much better result when compared to the traditional model based on neural network approach. The ANFIS model is better in terms of both time and accuracy. So, this model is accurate enough to measure the parameters of the monopole antenna which will be used for designing the antenna. Thus, ANFIS model not only eliminates the long time consuming process of finding various designing parameters using costly software packages like ANN model but also faster yielding more accurate results.

Keywords: *Monopole Antenna, Adaptive Neuro -Fuzzy Inference system, Back Propagation Algorithm, and neural Network.*

1. Introduction

Many emerging microwave techniques and applications aim at using ultrashort pulses on the order of nanoseconds. In the frequency domain, such signals occupy an ultra wideband (UWB) frequency spectrum. In 2002, US-FCC has assigned the frequency band of 3.1–10.6 GHz with respect to these emerging UWB activities. The primary objective of UWB is the possibility of achieving high data rate communication in the presence of existing wireless communication standards. For example, the recent IEEE protocol 802.11 g provides only 54 Mbps data rate. The use of UWB can give data rates of the order of hundreds of megabits per second. In addition to wireless communications, the use of UWB signals is envisaged in microwave imaging applications. This is motivated by the fact that such signals offer an increased resolution of imaged objects (Abbosh, A.M., 2008) .

Shortcoming of these planar UWB antenna designs is that they are based on the lengthy trial and error method that involves computationally intensive full wave electromagnetic simulations.

When one decides to design an antenna using different structures, the time consuming design process has to be fully repeated. In such circumstances, the designers are interested in having simple design formulas that provide a very good approximation to the final design when sophisticated EM analysis and design software packages are applied. The present paper addresses this issue and proposes two new techniques in soft computation to calculate the design parameters.

In this paper, a new method based on the adaptive neuro-fuzzy inference system (ANFIS) (J.-S.R. Jang,1993), (J.-S.R. Jang, C. T. Sun, and E. Mizutani,1997) is presented to calculate accurately the design parameters of the square monopole antenna and the results are compared with that of traditional model based on artificial neural network..

The ANFIS is a class of adaptive networks which are functionally equivalent to fuzzy inference systems (FISs). It combines the powerful features of FISs with those of artificial neural networks (ANNs). A hybrid learning algorithm) (J.-S.R. Jang,1993), (J.-S.R. Jang, C. T. Sun, and E. Mizutani,1997), which combines the least-square method and the backpropagation algorithm, is used to determine optimally the values of ANFIS parameters. Fast and accurate learning, excellent explanation facilities in the form of semantically meaningful fuzzy rules, the ability to accommodate both data and existing expert knowledge about the problem, and good generalization

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capability features have made neuro-fuzzy systems popular in recent years (J.-S.R. Jang,1993), (J.-S.R. Jang, C. T. Sun, and E. Mizutani,1997) (C. T. Lin and C. S. G. Lee, 1996).

Because of these attractive features, the ANFIS in this paper is used to model the relationship between the parameters of the square antenna and the measured resonant frequency results. Then the results are compared with results obtained by using artificial neural network which is already existing in literature.

The paper is organized as follows. Section II describes the design of antenna . Section III presents the models based on artificial intelligence to calculate the design papers of antenna. Section IV reports on experimental results and Section V concludes the findings of this paper.

2. Antenna Design

A versatile antenna which has large attention recently is Printed monopole antenna. They offer large bandwidth and are more attractive for wireless communication applications. The large ground plane used for the conventional Printed monopole is the main limitation. However, the move towards the truncated ground plane has made the antenna low profile and suitable for integration into circuit board as tenninal antennas . Recently printed antennas have received much attention due their low profile and omni-directional radiation characteristics. The rapid growth of Ultra Wide Band communication demands ultra wide band antennas to accommodate the large frequency spectrum of ultra short pulse used for this communication.

There is a growing demand for small and low cost UWB antennas that can provide satisfactory performances in both frequency domain and time domain.

A square plate simple monopole structure is shown in fig.1. The square plate monopole with a side of L_p and a 50Ω microstrip feed line are printed on the same side of the FR4 (Flame Resistant 4) substrate (the substrate has a thickness of *H*=1.6mm and a relative permittivity of ϵ_r=4.4).

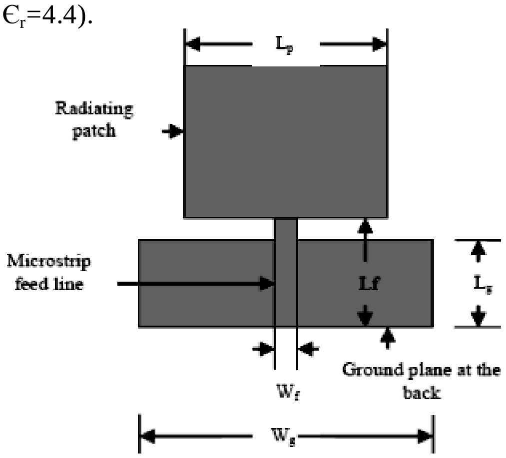

Fig.1. Geometry of microstrip feed line fed square monopole

Conducting ground plane is on the other side of the substrate whose length, L_g, can exceed maximum to the length of microstrip feed line, L_f, while width of the ground plane, W_g, can vary from a value greater than the width of microstrip feed line, W_f, to infinity. The various antenna designing parameters L_g, W_g, L_f, W_f and L_p, along with their positions can be varied for attaining different operating frequency, f_r.

In this work, different resonant frequency, f_r are obtained by varying the designing parameters of the above mentioned structure (Tanushree B**ose** and Nisha Gupta,2008). The data collected are used to prepare two different models based on ANN and ANFIS techniques discussed in the next section.

3. Development of Models based on artificial intelligence

Various techniques based on Artificial Intelligence are being invented to model and enable solutions to real world problems, which are not modeled, or too difficult to model, mathematically. These problems are typically associated with fuzzy, complex, and dynamical systems, with uncertain parameters. These systems are the ones that model the real world and are of most interest to the modern science. These models based on artificial intelligence are efficient enough to replace the costly software packages and long time consuming mathematical calculations. In this paper ,two models are proposed,developed and tested based on artificial intelligence to calculate the design parameters i.e. length and width of patch of the square monopole antenna. The other parameters such as length and width of ground plane,dielectric constant ,length and width of feedgap are kept constant. Both the models are trained with 400 sets of data i.e. the length of ground plane and position of feedgap is in the input layer and corresponding resonant frequency in the output layer. The performance goal is set to be 10^{-5} and epochs are set to be 1000.Both the models are trained with same data set received with the help of IE3D software. The epochs and performance goal are also kept same to give a common platform for comparison for the two developed models.

Development Of ANFIS Model

The ANFIS is a FIS implemented in the framework of an adaptive fuzzy neural network, and is a very powerful approach for building complex and nonlinear relationship between a set of input and output data years (J.-S.R. Jang,1993), (J.-S.R. Jang, C. T. Sun, and E. Mizutani,1997). It combines the explicit knowledge representation of FIS with the learning power of ANNs. Usually, the transformation of human knowledge into a fuzzy system (in the form of rules and membership functions) does not give exactly the target response. So, the optimum values of the FIS parameters should be found. The main objective of the ANFIS is to determine the optimum values of the equivalent FIS parameters by applying a learning algorithm using input-output data sets. The parameter optimization is done in such a way that the error between the target and the actual output is minimized. The ANFIS architecture consists of fuzzy layer, product layer, normalized layer, de-fuzzy layer, and summation layer. A typical ANFIS architecture is shown in Figure 2, in which a circle indicates a fixed node, whereas a square indicates an adaptive node. For simplicity, we assume that the FIS under consideration has two inputs x and y and one output z. The ANFIS used in this work implements a firstorder Sugeno fuzzy model. Among many FIS models, the Sugeno fuzzy model is the most widely applied one for its high interpretability and computational efficiency, and built-in optimal and adaptive techniques.

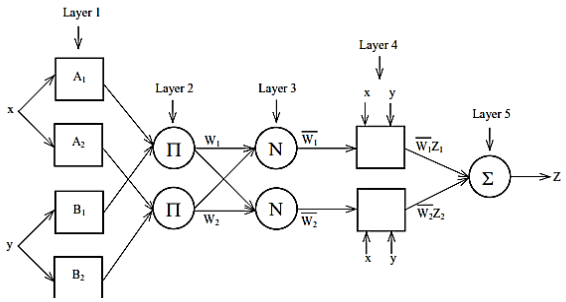

Fig.2 Architecture of ANFSI

The model in this paper is developed using a hybrid learning algorithm years (J.-S.R. Jang,1993), (J.-S.R. Jang, C. T. Sun, and E. Mizutani,1997), which combines the least-square method and the backpropagation algorithm. The model is trained with 400 sets of input/output data, which are obtained by interpolating 100 simulated data obtained from IE3D software, a commercial simulator based on moment of methods (MoM). The model is trained for giving dimension and position of radiating element i.e. L_p and (X_p, Y_p) for a desired frequency, ranging from 4.5 GHz to 8.9 GHz, keeping all other designing parameters (L_g, W_g, L_f, and W_f) constant at a fixed position.

The network is trained with least square algorithm, which has 5 member functions whose performance goal was taken as 10^{-5} and number of epochs 10000. For 400 input/ output training samples, the network requires only 1 minute for training .

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 ANFIS model*: We create a network consisting of an estimated number of layers and of an estimated number of neurons in the layers. The ANFIS architecture consists of fuzzy layer, product layer, normalized layer, de-fuzzy layer, and summation layer. A typical ANFIS architecture is shown in Figure 2, in which a circle indicates a fixed node, whereas a square indicates an adaptive node. For simplicity, we assume that the FIS under consideration has two inputs x and y and one output z. The ANFIS used in this work implements a first order Sugeno fuzzy model. Among many FIS models, the Sugeno fuzzy model is the most widely applied one for its high interpretability and computational efficiency, and built-in optimal and adaptive techniques. 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 ANFIS model:* During the training, input patterns are successively introduced into the inputs of the 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 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 ANFIS 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 designing parameter of an antenna for a desired frequency. That way, a computationally modest 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 a monopole antenna for a desired resonant frequency between 4.5 GHz and 8.9 GHz. The output parameters achieved from the network can be used for designing the monopole antenna for wideband application. The performance of the prepared model is discussed in the next section.

Development Of ANN Model

The model is developed using Feed Forward Back Propagation algorithm which has one input layer, one hidden layer and one output layer as shown in Fig.2. The model is trained with 400 sets of input/output data, which are obtained by interpolating 100 simulated data obtained from IE3D software, a commercial simulator based on moment of methods (MoM). The model is trained for giving dimension and position of radiating element i.e. L_p and (X_p, Y_p) for a desired frequency, ranging from 4.5 GHz to 8.9 GHz, keeping all other designing parameters (L_g, W_g, L_f, and W_f) constant at a fixed position.

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 designing parameter of an antenna for a desired frequency. That 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 a monopole antenna for a desired resonant frequency between 4.5 GHz and 8.9 GHz. The output parameters achieved from the network can be used for designing the monopole antenna for wideband application. The performance of the prepared model is discussed below.

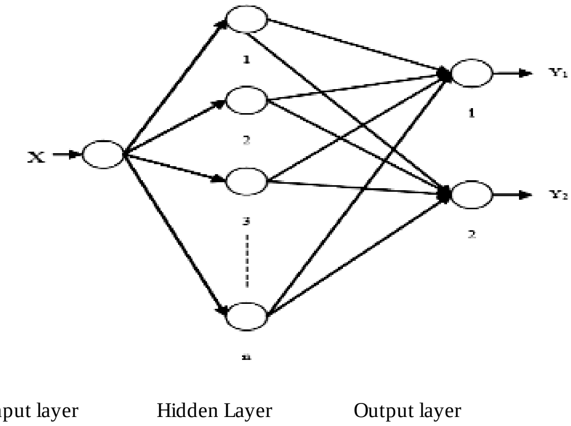

Fig.3 A feed forward network

4. Results And Discussion

Both the developed models based on ANN and ANFIS, have an excellent use in designing monopole antennas for wideband applications. For the sake of simplicity, the model is trained to give two output designing parameters [L_p and (X_p, Y_p)] for any desired operating frequency ranging between 4.5 GHz and 8.9 GHz, while all other designing parameters (L_g, W_g, L_f and W_f) are predetermined at a particular position as given below:

- The length of the ground plane, L_g= 20mm
- The width of the ground plane, W_g= 10mm
- The position of the ground plane, (X_g, Y_g)= (0,0)
- The length of the microstrip feed line, L_f = 10mm
- The width of the microstrip feed line, W_f = 10mm
- The position of the feed line, (X_f, Y_f)= (0,3)

The network is trained with least square algorithm, which has 5 member functions whose performance goal was taken as 10^{-5} and number of epochs 10000. For 400 input/ output training samples, the network requires only 1 minute for training and % error is found to lie within 0.2% to 5 %. Where % error is calculated by the following formula:

% Error = (Simulated Value – ANN Value)/Simulated value * 100

With the same data, there is another model prepared based on artificial neural network .The network is trained with backpropagation algorithm whose performance goal was taken as 10^{-5} and number of epochs 10000. For 400 input/ output training samples, the network requires almost 10 minutes for training and % error is found to lie within 0.2% to 5 %. A comparison between the two models along with the simulated value of IE3D software is presented below:-

Table1. Error measurement for the simulated f_r from IE3D and the ANN and ANFIS model

Input	**Result given by ANFIS model**		**Result given by ANN model**		**Result given by IE3D Software**		**Error percenage**	**Error percentage**
Resonant freq. (F_r), GHz	**Length and Width of ground plane (mm)**	**Patch position (x,y)**	**Length and Width of ground plane (mm)**	**Patch position (x,y)**	**Resonant Freq (F_r) (in GHz) ANFIS**	**Resonant Freq (F_r) (in GHz) ANN**	**ANFIS**	**ANN**
4.53	15.9840	0,15.9920	14.2345	0,15.1172	4.59795	4.67995	1.5	3.31
4.50	16.4279	0,16.2139	13.3816	0,14.6908	4.55695	4.74146	1.265	5.36
4.63	14.3778	0,15.1889	12.6464	0,14.3232	4.6697	4.81321	0.857	3.95
4.81	12.0454	0,14.0227	13.0352	0,14.5176	4.88497	4.75171	1.558	1.21
4.95	11.1362	0,13.5681	11.7966	0,13.8983	4.96697	4.90547	0.34	0.8995
5.12	9.9366	0,12.9683	9.5730	0,12.7865	5.12073	5.17198	0.014	1.015
5.34	8.7631	0,12.3816	11.5693	0,13.7846	5.31549	4.91572	0.458	7.945
5.55	7.8460	0,11.9230	10.8900	0,13.4450	5.4795	5.00797	1.270	9.766
5.11	10.0076	0,13.0038	17.6684	0,16.8340	5.11048	5.5205	0.0093	8.033
5.69	7.0626	0,11.5313	8.0294	0,12.0147	5.66401	5.44875	0.456	4.239
Mean error:							0.77	4.57

Both the models are tested for 10 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 ANFIS model and ANN model . From Table 1 one can estimate that the prepared network or model is accurate enough for determining the various design parameters of a monopole antenna operating between 4.5 GHz and 8.9 GHz. The above mentioned characteristics of the monopole antenna obtained from both the models are found to be acceptable within the error limit.But in case of ANFIS model, error percentage is much less as compared to the error percentage in case of ANN model. Thus this ANFIS model can be very well used for design of monopole antenna using FR4 sheet having a dielectric constant of 4.4. The antenna is designed using IE3D software and the designing parameters are obtained from the developed ANN and ANFIS model. ANFIS is much better than ANN in terms of time consumed for training the network.The comparison in terms of time is shown in the table below:

Table 2: Comparison of time taken for training the models

Models developed:	**Time Taken(Minutes)**
ANN	120 minutes
ANFIS	4 minutes

By increasing the number of training patterns and the member functions 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 100 simulated data obtained from the IE3D simulation, to get 400 data for training.

Conclusion

The trained networks are very useful as they give all the design parameters of the monopole antenna for any desired resonant frequency. A distinct advantage of these models is that, after proper training, they completely bypasses repeated use of complex iterative processes for new design presented to it. Out of the two models, the ANFIS model is much better than the ANN model as it reduces the error performance and it also reduces the training time. This work can be further extended by varying other designing parameters. Moreover, the model's efficiency can be increased by training it for variable dielectric constants and for different shapes of the radiating element.

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