ARTIFICIAL NEURAL DESIGN OF THE MICROSTRIP ANTENNAS

Nurhan Türker e-mail: nturker@yildiz.edu.tr
Filiz Güneş e-mail: gunes@yildiz.edu.tr
Tülay Yıldırım e-mail: tulay@yildiz.edu.tr
Yıldız Technical University, Electrical and Electronics Engineering Faculty, Department of Electronics and Communication Engineering, Yıldız, Istanbul, 34349, Turkey

Key words: Rectangular microstrip antennas, artificial neural networks, reverse modeling

ABSTRACT

In this work, a general design procedure is suggested for the microstrip antennas using artificial neural networks and this is demonstrated using the rectangular patch geometry. In this design procedure, synthesis is defined as the forward side and then analysis as the reverse side of the problem. Worked examples are given using the most efficient materials.

I. INTRODUCTION

In high-performance spacecraft, aircraft, missile and satellite applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, and low profile antennas may be required. Presently there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet these requirements, microstrip antennas can be used [1]. These antennas are low-profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when particular patch shape and mode selected they are very versatile in terms of resonant frequency, polarization, pattern and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency; impedance; polarization and pattern can be adjusted [2].

Often microstrip antennas are also referred as patch antennas because of the radiating elements (patchs) photoetchen on the dielectric substrate. This radiating patch may be square, rectangular, circular, elliptical, triangular, and any other configuration. In this work, rectangular microstrip antennas are the ones under consideration (Figure 3). Patch dimensions of rectangular microstrip antennas are usually designed so its pattern maximum is normal to the patch. Because of their narrow bandwidths and effectively operating in the vicinity of resonant frequency, the choice of the patch dimensions giving the specified resonant frequency is very important. In literature, artificial neural network (ANN) models have been built usually for the analysis of the microstrip antennas in various forms such as rectangular, circular, equilateral triangle patch antennas [4-7]. In these works, analysis problem can be defined as to obtain resonant frequency for a given dielectric material and geometric structure (Figure 2). However in this work, the corresponding synthesis ANN model is built to obtain patch dimensions of rectangular microstrip antennas (*W,L*) as the function of input variables, which are the height of the dielectric substrate (h), dielectric constants of the dielectric material ($\varepsilon_r, \varepsilon_y$) and the resonant frequency (f_r)(Figure1). This synthesis problem is solved using the electromagnetic formulae of the microstrip antennas. In this formulation two points are especially emphasized: One is the resonant frequency of the antenna and the other is the condition for the good radiation efficiency. Using the reverse modeling, an analysis ANN is built to find out the resonant frequency immediately for a given rectangular microstrip antenna system. The models are simple, easy to apply and very useful for antenna engineers to predict both patch dimensions and resonant frequency. So in the following sections, the forward and reverse sides of this design problem are defined as the black-ANN boxes; then the electromagnetic background is briefly summarized for building the synthesis ANN model. In the following section, also, this synthesis model is reversed for the analysis purpose of the given antenna system whose results are compared with the ones existing in the literature.

II. DESIGN PROBLEM FOR THE MICROSTRIP ANTENNA

In this work, patch geometry of the microstrip antenna is obtained as the function of input variables, which are height of the dielectric material (h), dielectric constants of the substrate material ($\varepsilon_r, \varepsilon_y$) and the resonant frequency (f_r) using the ANN techniques (Figure1). Similarly, in the analysis ANN, resonant frequency of the antenna is obtained as the function of patch dimensions (*W, L*), height of the dielectric substrate (h) and dielectric constants of the material ($\varepsilon_r, \varepsilon_y$) (Figure2).

Thus forward and reverse sides of the problem will be defined for the rectangular patch geometry in the following subsections.

THE FORWARD SIDE OF THE PROBLEM: THE SYNTHESIS ANN

The input quantities to the ANN black-box in synthesis (Figure1) can be ordered as:

- *h*: height of the dielectric substrate;
- $\varepsilon_r, \varepsilon_y$: electrical properties of the dielectric substrate where $\varepsilon_r, \varepsilon_y$ are the permittivities in the x and y directions of the dielectric material used in the system, respectively;
- f_r : resonant frequency of the antenna.

The following quantities can be obtained from the output of black-box as the functions of the input variables:

- W : width of the patch;
- L : length of the patch.

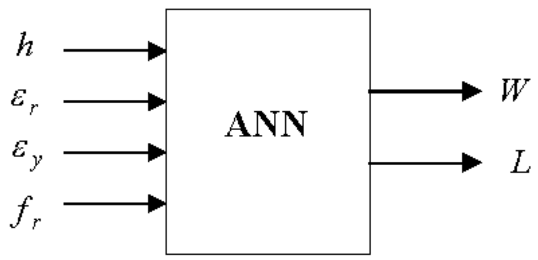

Figure 1. The synthesis ANN model

THE REVERSE SIDE OF THE PROBLEM: THE ANALYSIS ANN

In the analysis side of the problem, the similar terminology to the synthesis mechanism is used, but the resonant frequency of the antenna is obtained from the output for a chosen dielectric substrate and patch dimensions at the input side (Figure 2).

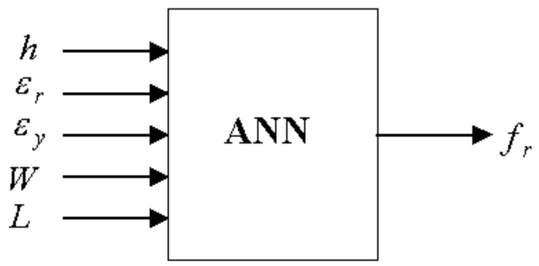

Figure 2. The analysis ANN model.

III. ELECTROMAGNETIC WORKING OF MICROSTRIP ANTENNAS

Microstrip patch antennas which are the most common printed-board radiating elements at RF and microwave frequencies, have two basic models to explain electromagnetic working: (i) Transmission line; (ii) Cavity. Both of them give good physical insight; however the cavity model is more accurate, at the same time more complicated. Later a full-wave analysis has been developed including primarily the integral equations/moment methods to treat accurately single elements as well as finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling.

In recent decade, neural network models have been developed especially for the calculation of resonant frequencies for the various shapes of antennas such as equilateral triangular, circular, rectangular microstrip antennas respectively in [4-9]. The accurate evaluation of the resonant frequency of microstrip antennas is a key factor to determine their correct behaviours. Training and test data sets used for these ANN models were obtained as either analytical or measured from the previous works in literature. ANN models developed for the evaluation of the input impedances of microstrip antennas are also available in literature [10], [11]. There is also a fast technique to evaluate the resonant frequency of microstrip antennas using neuro-fuzzy networks [12]. In [13] and [14], a neural technique is combined with the spectral (wavenumber domain) analysis together resulting "Neurospectral" analysis to apply the square-patch antenna basically for analysis but then reversing the model for the synthesis of the antenna. Another work for ANNs in use of reverse modeling is its utilization as the function/inverse function approximators for RF/Microwave transmission line design problems [15].

RECTANGULAR MICROSTRIP ANTENNAS

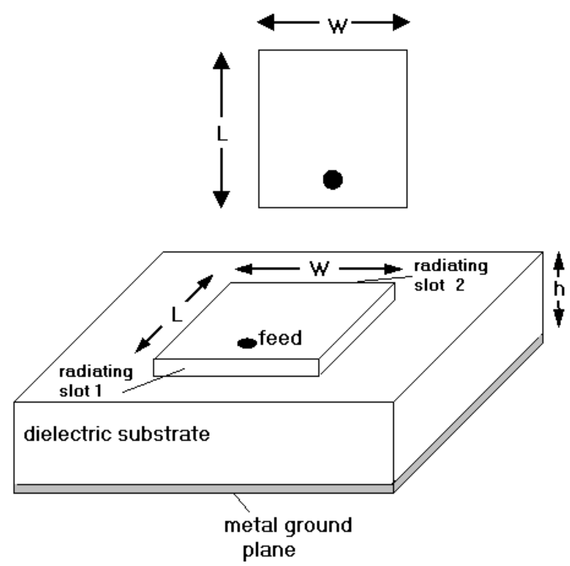

Figure 3. Rectangular microstrip antenna.

The rectangular microstrip antennas are made of a rectangular patch with dimensions, width, W, and length, L, over a ground plane with a substrate thickness h and dielectric constants $\varepsilon_r, \varepsilon_y$, as given in Figure 3. Dielectric constants are usually used in the range of $2.2 \le \varepsilon_r \le 12$. However, the most desirable ones are the dielectric constants in the lower end of this range together with the thick substrates, because they provide better efficiency, larger bandwidth, but at the expense of larger element size [3].

In literature, almost all works have been done by choosing the dielectric subtrate to be in isotropic structure. In this work, the ANN model is capable of giving results for both isotropic and anisotropic structures of the dielectric substrate. For an anisotropic substrate, the spacing parameter h is replaced by the effective spacing h_e and the geometric mean ε_g is used for the dielectric constant $\boldsymbol{\varepsilon_r}$:

$$h_e = \sqrt{\frac{\varepsilon_r}{\varepsilon_y}}h, \quad \varepsilon_g = \sqrt{\varepsilon_r \varepsilon_y} \qquad (1), (2)$$

The effective dielectric constant of the dielectric material is given in (3).

$$\varepsilon_{eff} = \frac{\varepsilon_g + 1}{2} + \frac{\varepsilon_g - 1}{2}[1 + 12\frac{h_e}{W}]^{-1/2} \qquad (3)$$

For an efficient radiator, a practical width that leads to good radiation efficiencies is [2]:

$$W = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_g + 1}} \qquad (4)$$

where v_o is the free-space velocity of light.

The actual length of the patch:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\mu_o \varepsilon_o}} - 2\Delta L \qquad (5)$$

where ΔL is the extension of the length due to the fringing effects and is given by:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (6)$$

IV. BUILDING NEURAL NETWORKS FOR THE RECTANGULAR MICROSTRIP ANTENNA AND RESULTS

In this work, both Multilayer Perceptron (MLP) and Radial Basis Function (RBF) networks were used in ANN models. MLP models were trained with almost all network learning algorithms. Among all these, the ones giving the best results for MLP network has been shown in Table 1. MLP network, which has configuration of 4 input neurons, 10 and 5 neurons in two hidden layers, and 2 output neurons with learning rate=0.1, goal=0.001, was trained for 400 epochs. Hyperbolic tangent sigmoid and linear transfer functions were used in MLP training. In RBF network, spread value was chosen as 0.01 which gives the best accuracy. Both MLP and RBF were trained with 45 samples and tested with 15 samples determined according to the definition of the problem; 4 inputs and 2 outputs were used for the analysis ANN and 5 inputs and 1 output for the synthesis ANN.

In 1991, Park and Sandberg proved the universal approximation theorem for RBF networks [16]. According to their work, a RBF neural network with a sufficient number of hidden layers is capable of approximating any given nonlinear function to any degree of accuracy. In Table 1, the accuracy values of analysis ANN for four networks giving the best results have been given. As can be seen from Table 1 and Table 4, in synthesis and analysis, RBF network were the one giving the best approximation to the target values whose structure is defined in the following subsection. The results of the synthesis and analysis ANN and comparison with the targets are given in Table 2 and 3, respectively. The train and test data of the synthesis and analysis ANN were obtained from both experimental results given in previous works [6] and a computer program using formulae given in Section 3 [2]. The data are in a matrix form consisting inputs and target values and arranged according to the definitions of the problems.

Table 1. Accuracies of the synthesis ANN for four networks giving the best results

	% Accuracy
RBF	99.09
MLP 1	96.53
MLP 2	95.05
MLP 3	94.88

RBF: Radial basis function network.
MLP 1: Multilayer perceptron network using scaled conjugate gradient backpropagation as learning algorithm.
MLP 2: Multilayer perceptron network using resilient backpropagation algorithm as learning algorithm.
MLP 3: Multilayer perceptron network using Levenberg-Marquardt optimization algorithm as learning algorithm.

Table 2. Results of the synthesis ANN and comparison with the targets.

h(cm)	ε_r	f_r***(GHz)***	***W-target(cm)***	***W-RBF(cm)***	***L-target(cm)***	***L-RBF(cm)***
0.3175	2.33	2.310	5.7000000e+000	5.6974505e+000	3.8000000e+000	3.7994597e+000
0.3175	2.33	2.890	4.5500000e+000	4.5474521e+000	3.0500000e+000	3.0499109e+000
0.3175	2.33	4.240	2.9500000e+000	2.9511621e+000	1.9500000e+000	1.9486281e+000
0.3175	2.33	5.840	1.9500000e+000	1.9475063e+000	1.3000000e+000	1.2971094e+000
0.3175	2.33	6.800	1.7000000e+000	1.6944723e+000	1.1000000e+000	1.1033160e+000
0.3175	2.33	7.700	1.4000000e+000	1.3929305e+000	9.0000000e-001	9.0775583e-001
0.3175	2.33	8.270	1.2000000e+000	1.1977494e+000	8.0000000e-001	7.9030186e-001
0.3175	2.33	9.140	1.0500000e+000	1.0426235e+000	7.0000000e-001	7.0188779e-001
0.9525	2.33	4.730	1.7000000e+000	1.7005360e+000	1.1000000e+000	1.1001805e+000
0.4000	2.55	7.134	7.9000000e-001	7.9083561e-001	1.2550000e+000	1.2579399e+000
0.4500	2.55	6.070	9.8700000e-001	9.8108696e-001	1.4500000e+000	1.4564505e+000
0.4760	2.55	5.820	1.0000000e+000	1.0135424e+000	1.5200000e+000	1.5142246e+000
0.4760	2.55	6.380	8.1400000e-001	8.1739191e-001	1.4400000e+000	1.4414665e+000
0.5500	2.55	5.990	7.9000000e-001	7.8253575e-001	1.6200000e+000	1.6187765e+000
0.1570	2.33	5.060	1.7200000e+000	1.7173371e+000	1.8600000e+000	1.8634147e+000

Table 3. Results of the analysis ANN and comparison with the targets.

h(cm)	ε_r	***W (cm)***	***L (cm)***	f_r ***-target(GHz)***	f_r ***-RBF(GHz)***
0.3175	2.33	5.7	3.80	2.3100000e+000	2.3108710e+000
0.3175	2.33	4.55	3.05	2.8900000e+000	2.8880900e+000
0.3175	2.33	2.95	1.95	4.2400000e+000	4.2060612e+000
0.3175	2.33	1.95	1.30	5.8400000e+000	5.8893107e+000
0.3175	2.33	1.70	1.10	6.8000000e+000	6.6958903e+000
0.3175	2.33	1.40	0.90	7.7000000e+000	7.7905070e+000
0.3175	2.33	1.20	0.80	8.2700000e+000	8.3661174e+000
0.3175	2.33	1.05	0.70	9.1400000e+000	9.0719890e+000
0.9525	2.33	1.70	1.10	4.7300000e+000	4.6866520e+000
0.4000	2.55	0.79	1.255	7.1340000e+000	7.0603068e+000
0.4500	2.55	0.987	1.45	6.0000000e+000	6.0940227e+000
0.4760	2.55	1.00	1.52	5.8200000e+000	5.8599528e+000
0.4760	2.55	0.814	1.44	6.3800000e+000	6.4233684e+000
0.5500	2.55	0.79	1.62	5.9900000e+000	5.9439372e+000
0.1570	2.33	1.72	1.86	5.0600000e+000	5.0258464e+000

Table 4. Accuracies of the analysis ANN for four networks giving the best results

	% Accuracy
RBF	97.76
MLP 3	97.75
MLP 2	96.68
MLP 1	95.85

RBF NETWORKS

Feedforward neural networks with a single hidden layer that use radial basis activation functions for hidden neurons are called radial basis function networks. RBF network are applied to various microwave modeling purposes. A typical RBF network structure is given in Figure 4. The parameters c_{ij} and λ_{ij} are centers and standard deviations of radial basis activation functions. Commonly used radial basis activation functions are gaussian and multiquadratic.

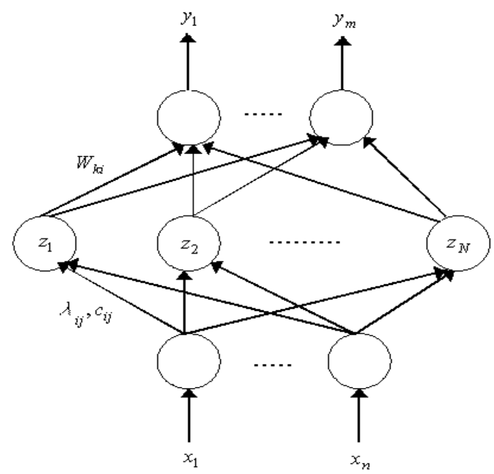

Figure 4. RBF neural network structure.

Given the inputs **x**, the total input to the *i*th hidden neuron γ_i is given by

$$\gamma_i = \sqrt{\sum_{j=1}^{n}\left(\frac{x_j - c_{ij}}{\lambda_{ij}}\right)^2}, i = 1,2,....., N \quad (7)$$

where N is the number of hidden neurons. The output value of the *i*th hidden neuron is $zij = \sigma(\gamma_i)$, where $\sigma(\gamma)$ is a radial basis function. Finally, the outputs of the RBF network are computed from hidden neurons as

$$y_k = \sum_{i=0}^{N} w_{ki} \; z_{ki} \quad (8)$$

where w_{ki} is the weight of the link between *i*th neuron of the hidden layer and *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 [17].

V. CONCLUSION

In this work, the neural network is employed as a tool in design of the microstrip antennas. In this design procedure, synthesis is defined as the forward side and then analysis as the reverse side of the problem. Therefore one can obtain the geometric dimensions with high accuracy, which are the length and the width of the patch in our geometry, at the output of the synthesis network by inputting resonant frequency, height and dielectric constants of the chosen substrate. Furthermore in our work, the synthesis can also be applied into anisotropic dielectric substrate. In this work the analysis is considered as a final stage of the design procedure, therefore the parameters of the analysis ANN network are determined by the data obtained reversing the input-output data of the synthesis network. Thus, resonant frequency resulted from the synthesized antenna geometry is examined against the target in the analysis ANN network. Finally, in this work, a general design procedure for the microstrip antennas is suggested using artificial neural networks and this is demonstrated using the rectangular patch geometry.

REFERENCES

1. C. A. Balanis, Antenna Theory, John Wiley & Sons, Inc., 1997.
2. I. J. Bahl and P. Bhartia, Microstrip Antennas, Artech House, Dedham, MA, 1980.
3. D. M. Pozar, Microstrip Antennas, Proc. IEEE, Vol. 80, No.1, pp.79-81, January, 1992.
4. Ş. Sağıroğlu, K. Güney, Calculation of resonant frequency for an equilateral triangular microstrip antenna using artificial neural Networks, Microwave Opt. Technology Lett., Vol. 14, pp. 89-93, 1997.
5. Ş. Sağıroğlu, K. Güney and M. Erler, Resonant frequency calculation for circular microstrip antennas using artificial neural networks, International Journal of RF and Microwave Computer-Aided Engineering, Vol. 8, No. 3, pp. 270-277, 1998.
6. D. Karaboğa, K. Güney, Ş. Sağıroğlu and M. Erler, Neural computation of resonant frequency of electrically thin and thick rectangular microstrip antennas, Microwaves, Antennas and Propagation, IEE Proceedings-Vol. 146, No. 2, pp. 155 – 159, April 1999.
7. K. Güney, Ş. Sağıroğlu and M. Erler, Generalized neural method to determine resonant frequencies of various microstrip antennas, International Journal of RF and Microwave Computer-Aided Engineering, Vol. 12, No. 1, pp. 131-139, January 2002.
8. Ş. Sağıroğlu, K. Güney and M. Erler, Calculation of bandwidth for electrically thin and thick rectangular microstrip antennas with the use of multilayered perceptrons, International Journal of RF and Microwave Computer-Aided Engineering, Vol. 9, No. 3, pp. 277-286, May 1999.
9. R.K. Mishra, A. Patnaik, Neural network-based CAD model for the design of square-patch antennas, Antennas and Propagation, IEEE Transactions, Vol. 46, No. 12, pp. 1890 – 1891, December 1998.
10. S. Devi, D.C. Panda and S.S. Pattnaik, A novel method of using artificial neural networks to calculate input impedance of circular microstrip antenna, Antennas and Propagation Society International Symposium, Vol. 3, pp. 462 – 465, 16-21 June 2002.
11. K. Güney, N. Sarıkaya, Artificial neural networks for calculating the input resistance of circular microstrip antennas, Microwave and Optical Technology Letters, Vol. 37, No. 2, pp. 107-111, 20 April 2003.
12. G. Angiulli, M. Versaci, Resonant frequency evaluation of microstrip antennas using a neural-fuzzy approach, Magnetics, IEEE Transactions, Vol. 39, No. 3, pp. 1333 – 1336, May 2003.
13. R.K. Mishra, A. Patnaik, Neurospectral computation for input impedance of rectangular microstrip antenna, Electronics Letters, Vol. 35, No. 20, pp. 1691 – 1693, 30 Sept. 1999.
14. R.K. Mishra, A. Patnaik, Designing rectangular patch antenna using the neurospectral method, Antennas and Propagation, IEEE Transactions, Vol. 51, No. 8, pp. 1914 – 1921, Aug. 2003.
15. N. Türker, F. Güneş, Neural Networks in Use of Function/Inverse Function Approximators for RF/Microwave Transmission Line Problems, accepted for publication in the proceedings of Int. Symposium on Innovations in Intelligent Systems and Applications, June 15-18, 2005, Istanbul, Turkey.
16. J. Park and W. I. Sandberg, Universal Approximation Using Radial Basis Function Networks, Neural Computation, Vol. 3, pp. 246-257, 1991.
17. Q. J. Zhang and K. C. Gupta, Neural Networks for RF and Microwave Design, Artech House Publishers, 2000.