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COMPUTATION OF RADIATION EFFICIENCY FOR A RESONANT RECTANGULAR MICROSTRIP PATCH ANTENNA USING BACKPROPAGATION MULTILAYERED PERCEPTRONS

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ABSTRACT

A new approach based on artificial neural networks for calculating the radiation efficiency of a rectangular microstrip antenna is presented. The backpropagation algorithm is used to train the networks. The method is valid for substrates with relative permittivities between 1 and 12.8 and for the complete range of thicknesses normally used. The results obtained by using this new method are in conformity with those reported elsewhere. The method can also be used in the calculation of the radiation efficiency of dipoles.

Keywords: *Radiation efficiency, artificial neural network, rectangular microstrip antenna.*

I. INTRODUCTION

Knowledge of radiation efficiency relating the power radiated in space waves to the total radiated power (including surfaces waves) is required for an efficient use of microstrip antennas. The surface waves exist due to the interface between air and the dielectric substrate that separates the radiating element from the ground plane. In general, if the thickness of the substrate on which the antenna is etched is very small compared to the wavelength of interest, the power propagated via the surface wave modes is negligible so that the effects of the substrate on the efficiency may be ignored. However, for an antenna radiating at the resonance of higher order modes the radiation efficiency decreases as some power propagates via surface wave modes.

A number of investigators [1-10] have determined surface wave effect. The most important of the results published is by Pozar [5]. The radiation efficiency data were

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calculated in [5] using a moment method solution of a printed rectangular radiating element on a grounded dielectric slab. James and Henderson [2] estimated that surface wave excitation is not important if $h/\lambda_0<0.09$ for $\varepsilon_r \cong 2.3$ and $h/\lambda_0<0.03$ for $\varepsilon_r \cong 10$, where h is the thickness of the dielectric substrate, λ_o is the free-space wavelength and ε_r is the relative dielectric constant of the dielectric substrate. The criterion presented by Wood [3] is more quantitative: $h/\lambda_o<0.07$ for $\varepsilon_r=2.3$ and $h/\lambda_0<0.023$ for $\varepsilon_r=10$ if the antenna is to launch no more than 25% of the total radiated power as surface waves. Rana and Alexopoulos [4] used the method of moments for the current distribution and surface wave power of a printed dipole. Perlmutter et al. [6] derived the surface wave power of a microstrip rectangular element, based on the electric current distribution on the upper surface of the element. They included only the TM_0 mode, which limits their results to substrates with small thicknesses. However, they considered cases other than those considered by Pozar [5]. Bhattacharyya and Garg [7] proposed a general approach for the determination of power radiated via the space wave and surface wave from the aperture of an arbitrarily shaped microstrip antenna. The magnetic current model has been used for this, and the analysis has been carried out in the Fourier domain to determine the effect of the substrate. The results obtained by Bhattacharyya and Garg [7] confirmed the results obtained by Pozar [5], but they did not provide extra material. Nauwelaers and Van De Capelle [8] presented a formula for the radiation efficiency of rectangular microstrip antennas. Guney [9-10] proposed simple closed-form expressions for the space wave efficiency of rectangular and circular microstrip antennas. These expressions were derived from numerical results available in the literature and provide insight into the fundamental influence of the substrate parameters on the space wave efficiency.

From the studies cited above we see that the certain way of calculating the radiation efficiency of rectangular microstrip antennas involves the complicated Green's function and integral transformation methods. Exact mathematical formulations in these methods involve extensive numerical procedures, resulting in round-off errors, and may also need final experimental adjustments to the theoretical results. Therefore, these methods suffer from a lack of computational efficiency, which in practice can restrict their usefulness because of high computational time and costs.

Ability to learn, generalization adaptability, smaller information requirement, fast real-time operation, and ease of implementation features have made ANNs popular in the last few years [10-12]. Because of these fascinating features, ANNs have been used for analysis of arbitrarily shaped microstrip antennas with a very general bianisotropic grounded slab [13]. On design side, the works of Mishra and Patnaik [14,15] are limited. In these works, the patch radius of the circular microstrip antenna or the patch length of the rectangular microstrip antenna has been approximated. In previous works [16-24], we also successfully introduced the artificial neural models to compute the bandwidth, the resonant resistance and the resonant frequencies of microstrip antennas. However, the research using neural network techniques should be able to demonstrate a mapping from input parameters to output parameters. Multilayered perceptrons (MLPs) in this article are used to calculate the radiation efficiency of rectangular microstrip antennas. First, the antenna parameters related to the radiation efficiency are determined, the radiation efficiency depending on these parameters are then calculated by using the neural model. The results obtained from this neural model are in very good agreement with the results available in the literature even when $h(\varepsilon_r)^{1/2}/\lambda_0= 0.36$.

2. RADIATION EFFICIENCY OF RECTANGULAR MICROSTRIP ANTENNAS

Consider a rectangular patch of width W and length L over a ground plane with a substrate of thickness h and a relative dielectric constant ε_r, as shown in Fig.1. The radiation efficiency due to surface waves is defined as follows

$$\eta = \frac{P_{sp}}{P_{sp} + P_{su}} \tag{1}$$

where P_{sp} is the power radiated in space waves and P_{su} is the power radiated in surface waves.

P_{sp}+P_{su} is then the total power delivered to the printed antenna element. Although P_{sp} is easily found, P_{su} has to be obtained using complicated Green function methods and integral transformation techniques.

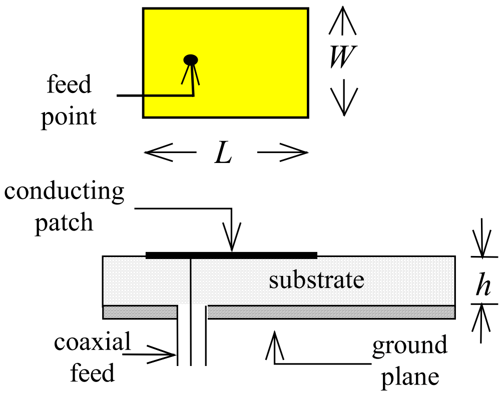

Figure 1. Geometry of rectangular microstrip antenna.

In this study, to determine the radiation efficiency of a rectangular microstrip antenna we will concentrate on the radiation efficiency results reported by Pozar [5] and Perlmutter et al. [6], because their results agree with those presented by other scientists in the literature. From the results of the methods [5-6] we see that as the thickness increases the radiation efficiency decreases, a lower value of ε_r results in a higher efficiency and the width W of the patch has almost no effect on the value of η. As we are only interested in resonant antennas, the physical length L of the patch is not of importance; it is determined by

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_e}} - 2\Delta L \tag{2}$$

where c is the velocity of electromagnetic waves in free space, ε_e is the effective relative dielectric constant for the patch, f_r is the resonant frequency, and ΔL is the edge extension. ε_e and ΔL depend on ε_r, h and W. Thus, the length L is determined by W, h, ε_r and f_r. Therefore, only two parameters are needed to describe the radiation efficiency, ε_r and h/λ_0. These parameters are used for the neural calculation of the radiation efficiency. This new model does not require neither the Green function methods nor the integral transformation techniques.

In the following sections, the backpropagation (BP) multilayered perceptron network used in this paper is briefly described and the neural model for calculating the radiation efficiency of a microstrip antenna is then explained.

3. BACKPROPAGATION MULTILAYERED PERCEPTRON NETWORK

Multilayered perceptrons (MLPs) [11], which are the simplest and therefore most commonly used neural network architectures, have been adapted for the calculation of the radiation efficiency of the microstrip antenna. MLPs can be trained using many different learning algorithms. In this work, the standard BP algorithm [12] has been used for training. An MLP consists of three layers: an input layer, an output layer and an intermediate or hidden layer. Processing elements (PEs) or neurons in the input layer only act as buffers for distributing the input signals x_i to PEs in the hidden layer. Each PE j in the hidden layer sums up its input signals x_i after weighting them with the strengths of the respective connections w_{ji} from the input layer and computes its output y_j as a function f of the sum, namely

$$y_j = f(\sum w_{ji} x_i) \tag{3}$$

f can be a simple threshold function, a sigmoidal or hyperbolic tangent function. The output of PEs in the output layer is computed similarly.

Training a network consists of adjusting weights of the network with the use of the standard BP algorithm. The BP algorithm, a gradient descent algorithm, is the most commonly adopted MLP-training algorithm. It gives the change $\Delta w_{ji}(k)$ in the weight of a connection between PEs i and j as follows,

$$\Delta w_{ji}(k) = \eta \delta_j x_i + \alpha \Delta w_{ji}(k-1) \tag{4}$$

where x_i is the input, η is a parameter called the learning coefficient, α is the momentum coefficient, and δ_j is a factor depending on whether PE j is an output PE or a hidden PE. For output PEs,

$$\delta_j = \frac{\partial f}{\partial \mathrm{net}_j}(y_j^T - y_j) \qquad (5)$$

where $\mathrm{net}_j \equiv \sum x_i w_{ji}$ and y_j^T is the target output for PE j. For hidden PEs,

$$\delta_j = \left(\frac{\partial f}{\partial \mathrm{net}_j}\right)\sum_q w_{qj}\delta_q \qquad (6)$$

As there are no target outputs for hidden PEs in eq.(6), the difference between the target and actual output of a hidden PE j is replaced by the weighted sum of the δ_q terms already obtained for PEs q connected to the output of j. Thus, iteratively, beginning with the output layer, the δ term is computed for PEs in all layers and the weights are updated for all connections according to eq.(4).

4. NEURAL MODEL FOR CALCULATING RADIATION EFFICIENCY AND SIMULATION RESULTS

The method proposed here involves training an MLP to calculate the radiation efficiency η when the values of ε_r and h/λ_0 are given. Figure 2 shows the neural model used in neural computation of the η. In Figure 2, LF and TF represent the linear transfer function and the tangent hyperbolic function used in the MLP structure, respectively. Training an MLP with the use of the BP to compute η involves presenting it sequentially with different sets (ε_r, h/λ_0) and corresponding target values η. Differences between the target output and the actual output of the MLP are backpropagated through the network to adapt its weights using eqns.(4)-(6). The adaptation is carried out after the presentation of each set (ε_r, h/λ_0) until the calculation accuracy of the network is deemed satisfactory according to some criterion (for example, when the root-mean-square (rms) error between the target output and the actual output for all the training set falls below a given threshold) or the maximum allowable number of epochs is reached.

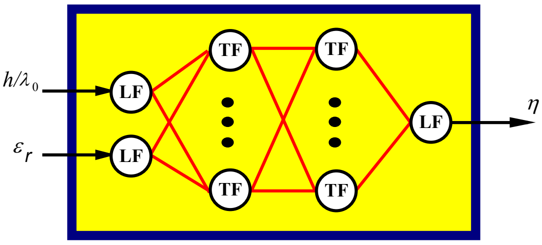

Figure 2. A neural model for calculation of the radiation efficiency of a rectangular microstrip antenna

A set of random values distributed uniformly between -0.1 and +0.1 was used to initialise the weights of the networks. However, the tuples were scaled between -1.0 and +1.0 before training. The neural models used in this paper had two hidden layers as this number of hidden layers should be sufficient for a neural network to perform arbitrary calculations. The adaptation has been carried out after the presentation of each input tuple (h/λ_o, ε_r and η) until the rms error in learning was less than 0.007 and 0.008 for the first and the second test cases given below, respectively.

There are no available methods to estimate the parameters of the BP algorithm properly for this specific application so the parameters are selected by experience on the algorithm and the problem.

The data sets used for training and test were obtained from the moment method approach [5] for ε_r=12.8 and the electric surface current model [6] for ε_r=2.2, 4.0, and 9.8. These data sets were used in two different cases to train and test the performance of ANNs.

The first case: 113 data sets obtained from [5] for ε_r=12.8, and from [6] for ε_r=2.2 and 4.0 were used to train the networks. 49 data sets obtained from [6] for ε_r=9.8 were used to test the performance of the networks. During training, the learning and momentum coefficients were set to 0.2 and 0.3, respectively. The seed number was also fixed to 1.0. The number of training epoch selected was 60.000. The most suitable network configuration found was six for the both hidden layers.

Figure 3 shows the test results. The solid curves in Figure 3 represent the results obtained with the neural model. It can be clearly seen from Figure 3 that the outputs of neural model were almost similar with the patch results. The total rms errors obtained were 0.007 for training and 0.009 for test.

The second case: Total 162 data sets obtained from [5] for ε_r=12.8, and from [6] for ε_r=2.2, 4.0 and 9.8 were used to train and test the neural models. 83 of these data sets were selected randomly from the total set and used to train the neural models. The rest of the data sets, 79, were used to test the performance of the networks. During training, the both learning and momentum coefficients were set to 0.1. The seed number was also fixed to 1.0. The number of training epoch selected was 30.000. The most suitable network configuration found was five for the both hidden layers.

Figures 4-7 depict the test results achieved from the neural models for totally unknown inputs. It is very apparent from the figures that the radiation efficiency for wide and narrow patch antennas on substrate with different relative permittivities is performed in high accuracy. The rms errors obtained were 0.008 for training and 0.009 for test.

The results obtained from the both cases illustrate that the performances of the networks are quite robust and precise. Thus, the neural models achieve the calculation of the radiation efficiency for a resonant rectangular microstrip patch antenna with a very good agreement.

5. CONCLUSION

A method based on ANNs trained with the BP algorithm for calculating the radiation efficiency of a rectangular microstrip antenna has been presented. As can be seen from the Figs. 3-7, there is an excellent agreement with the data from the Green function methods. This excellent agreement supports the validity of neural models. When the results of neural models are compared with those by Pozar [5] and Perlmutter et al. [6], the error is within 0.009, which is tolerable for most design applications. As the difference between radiation efficiencies for the dipoles and patches are always less than 0.02, the proposed neural model can also be used for dipoles.

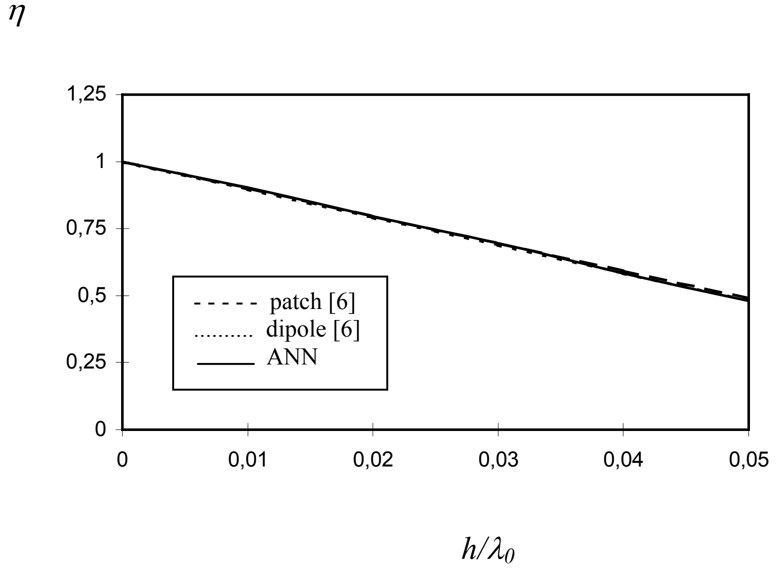

Figure 3. Test results of radiation wave efficiency for wide and narrow patch antenna on substrate with ε_r=9.8

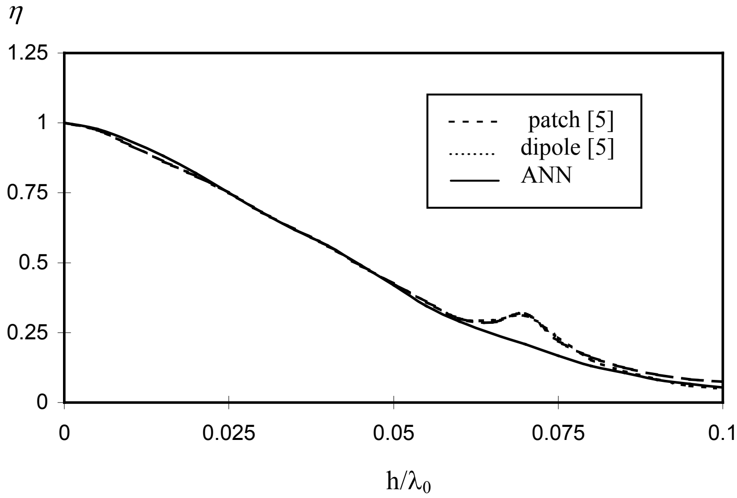

Figure 4. Test results of radiation efficiency for patch antenna and dipole on substrate with ε_r=12.8

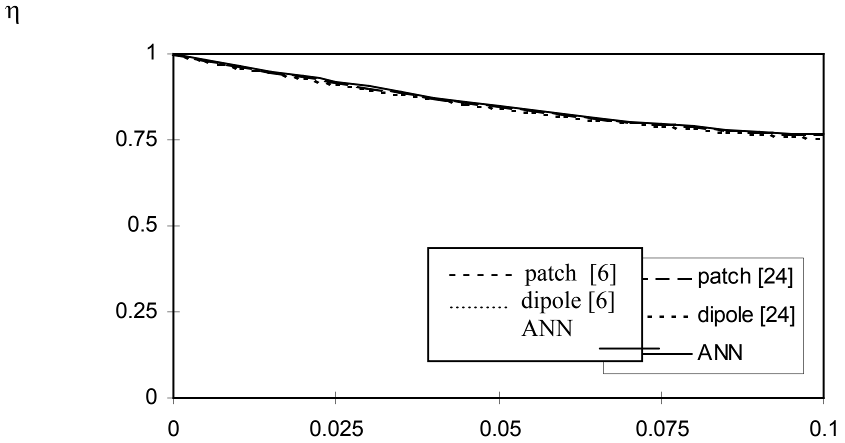

Figure 5. Test results of radiation efficiency for wide and narrow patch antenna on substrate with ε_r=2.2

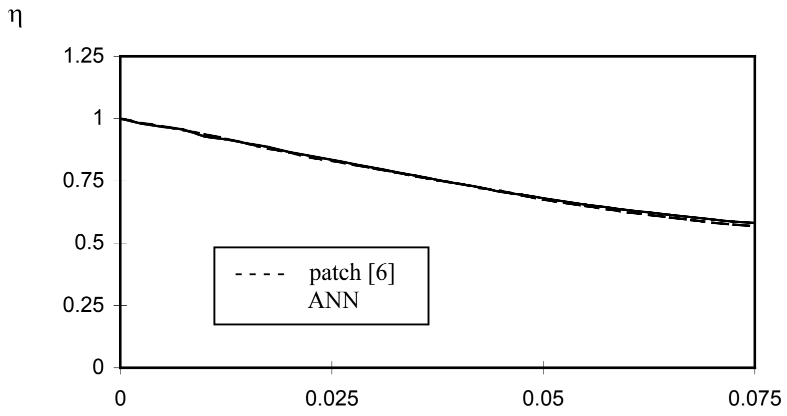

Figure 6. Test results of radiation efficiency for wide patch antenna on substrate with ε_r=4.0

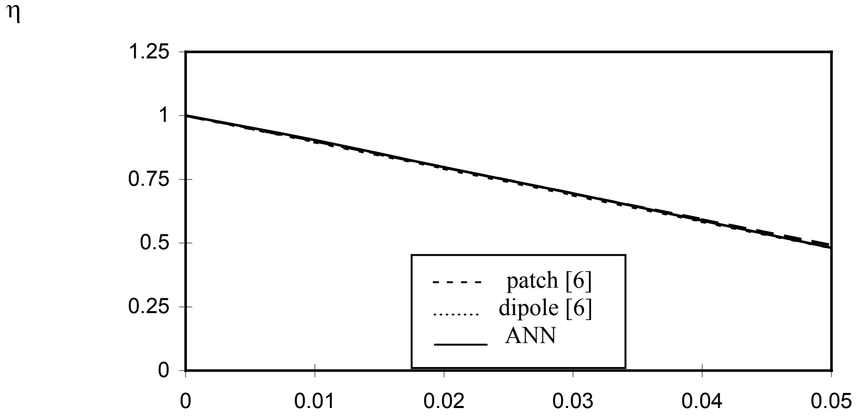

Figure 7. Test results of radiation wave efficiency for wide and narrow patch antenna on substrate with ε_r=9.8

Since the neural model presented in this work has high accuracy in the range of $2 \leq \varepsilon r \leq 12.8$ and $0 < h/\lambda d \leq 0.36$ and requires no complicated mathematical functions, it can be very useful for the development of fast CAD algorithms. This CAD model capable of accurately predicting the radiation efficiencies of rectangular microstrip antennas is also very useful to antenna engineers. Using this model, one can calculate accurately, by a personal computer (PC), the radiation efficiency of rectangular patch antennas, without possessing any background knowledge of microstrip antennas. It takes only a few microseconds to produce the radiation efficiency on a Pentium/500 MHz PC. Even if the training time takes less than ten minutes, after training, the calculation time is less than hundred microseconds in real time calculation. Thus, the neural model is very fast after training.

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