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Study of Rectangular U-slot microstrip patch antennas with artificial neural networks and their bandwidth model

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Abstract

In this paper, present bandwidth calculation of rectangular-slot microstrip antennas are achieved by the help of an Artificial Neural Network model trained. The antenna parameters are taken from in the literature. The experimental results are compared with Artificial Neural Network results. In comparison of the experimental and Artificial Neural Network results, accuracy rates of training and testing were found to be 98.6% and 93.3%, respectively. The ANN network is studied successfully for calculation of the band width values of rectangular U-slot microstrip antennas. It is obtained that Artificial Neural Network results are compatible with experimental bandwidth results from the literature. It is shown that possible bandwidth behavior of U-slot rectangular microstrip patch antennas with this Artificial Neural Network model is powerfully estimated.

Keywords: Rectangular U-slot; microstrip; patch antenna; bandwidth; ANN.

1. Introduction

Antenna is a transducer that converts one form into another and transmits or receives the electromagnetic waves. Microstrip antenna consists of radiating patch on one side of dielectric substrate and ground plane on the other side. Microstrip antennas printed directly onto a circuit board because of that they are very useful. Radiating patch is made of conducting material (copper or gold) with many different shapes like rectangular, circular, and elliptical and many more shapes. Microstrip antennas are one of the most popular type antennas, since they are lightweight, have simple geometries, are inexpensive to fabricate and can easily be made conformal to the host body. These attractive features have increased the application of microstrip antennas recently and stimulated greater efforts to investigate their performances[1-4].Microstrip patch antenna is used for high-performance spacecraft, aircraft, missile and satellite applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints. These patch antennas are low-profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed circuit technology. They are also mechanically robust when mounted on rigid surfaces and compatible with MMIC designs. When a particular patch shape and excited mode are selected they are very versatile in terms of resonant frequency, polarization, radiation pattern, and impedance.

Microstrip antennas suffer from low impedance bandwidth characteristics by the reason of increasing wideband applications. To overcome this handicap, there have been lots of studies on various bandwidth enhancement techniques like stacked patches, coplanar parasitic patches, or patches that have novel shapes such as the U and H-shaped patches [5-7]. Using special feed networks or feeding techniques to compensate for the natural impedance variation of the patch is another method [8-10]. Etching U-slot on the patch is may be the simple design [5-6]. This design avoids the use of stacked or coplanar parasitic patches, either of which increases the thickness or the lateral size of the antenna. So, while changing the current distribution on the microstrip patch, enhancing the impedance bandwidth with sometimes more than one resonant frequency are obtained. In 1995 a broad band single layer probe fed patch antenna with a U-shaped slot was presented by Huynh and Lee and wideband impedance characteristics were obtained by cutting a U-slot on the surface of the rectangular patch in [5-6]. In this paper, an Artificial Neural Network (ANN) is modeled with U-slot rectangular microstrip antenna parameters in the literature for calculation of their bandwidths. Here, the ANN results, experimental results from the literature are compared.

2. Rectangular microstrip patch antenna with U-slot

Rectangular microstrip antenna is the easiest geometry for designing and implementation. It is shown that etching U slot on rectangular patches enhance the impedance bandwidth up to 55% [5, 6]. By etching U slot, the impedance seen from the feed point will be changed and realizing impedance matching a larger bandwidth will be obtained. Generally, the enhancement process is realized by obtaining more than one resonant frequency that radiates under 10dB level [8-10]. The first resonance frequency is understood to be generated by the microstrip patch due to the physical parameters, while the second one by the U-shaped slots parameters [5-6]. The surface currents originate behind the U-slot, and are strong outside the U-slot arms [11]. The U slot introduces a capacitance and induces a second resonance frequency near the main resonance frequency of the microstrip patch, producing an enhanced frequency response [10]. The basic U-slot rectangular microstrip patch antenna design is seen in Figure 1. Here, L is the patch length, W is the patch width, F is the feed point, Ls is the vertical slot length, Ws is the horizontal slot length, t_L and t_W are slot widths in the vertical and horizontal, respectively.

3. Artificial neural networks

ANN is relativity crude electronic models based on the neural structure of the brain. The brain basically learns from experience. The researchers have successfully tried demonstrating certain level of intelligence on silicon. Artificial Neural Networks are biologically-inspired, intelligent techniques and they have a number of simple and highly interconnected layers of neurons. Multilayered perceptron neural networks (MLPNNs) are the simplest ANN architectures, and therefore most commonly used [12-14]. A MLPNN has mainly three layers: an input layer, an output layer, and an intermediate or hidden layer. The input layer neurons distribute the input signals x_i to neurons in the hidden layer(s). Each hidden layer neuron j 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_i as a function f of the sum:

$$y_j = f\left(\sum w_{ji} x_i\right) \quad (1)$$

Where, f is a sigmoid or hyperbolic tangent function. The output of neurons in the output layer is computed similarly.

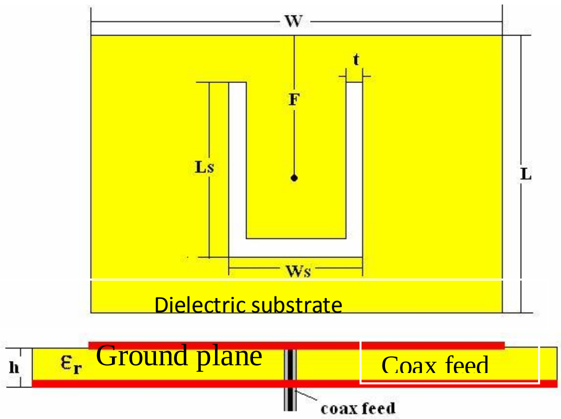

Figure 1. U slot loaded rectangular microstrip antenna.

Training a network consists of adjusting weights of the network using a learning algorithm. The Back-Propagation [15] learning algorithm is used in this study. It is a gradient descent algorithm that gives the change $\Delta w_{ji}\ (k)$ in the weight of a connection between neurons *i* and *j* as follows:

$$\Delta w_{ji}\ (k) = \alpha \delta_j x_i + \mu \Delta w_{ji}\,(k-1) \tag{2}$$

Where x_i is the input, α is the learning coefficient, μ is the momentum coefficient, and δ_i is a factor depending on whether neuron *j* is an output neuron or a hidden neuron. For output neurons,

$$\delta_j = \frac{\partial f}{\partial net_j}\left(y_j^T - y_i\right) \tag{3}$$

Here $net_j = \sum x_i\ w_{ji}$ and y_j^T is the target output for neuron *j*. For hidden neurons,

$$\delta_j = \frac{\partial f}{\partial net_j}\sum_q w_q \delta_q \tag{4}$$

As there are no target outputs for hidden neurons in Equation (4), the difference between the target and actual output of a hidden neuron j is replaced by the weighted sum of the δ_q terms already obtained for neurons q connected to the output of j. Thus, iteratively beginning with the output layer, the δ term is computed for all neurons in all layers except the input layer and weights were then updated according to Equation (2).

In the training of neural network, gradient descent with adaptive learning rate algorithm is used and K-fold cross-validation is used for the test result to be more valuable [16-22]. We used this method for finding the best ANN architecture. After training and test phase, the mean absolute error (MAE) and mean square error (MSE) calculation given in Equations (5) and (6) was used as performance criterion. Expressions in Equations (5-8) can be suggested for different ANN applications. In this study Equation (9) was arranged aiming to compare other literature studies.

$$\%MAE = \left(\frac{1}{n}\sum_{n=1}^{n}|t_i - t_h|\right) * 100 \tag{5}$$

$$\%MSE = \left(\frac{1}{n}\sum_{n=1}^{n}(t_i - t_h)^2\right) * 100 \tag{6}$$

Here, t_i are the desired outputs values, t_h are the ANN output values and *n* is the data number.

In addition, the test results satisfying the minimum errors were subjected to *r*-square correlation test given in Equations (7) and (8). These correlation values were used as another criterion for the determination of optimum ANN structure:

$$r = \frac{\sum(t_i-\bar{t_i})(t_h-\bar{t_h})}{\sqrt{(t_i-\bar{t_i})^2\,(t_h-\bar{t_h})^2}} \quad (7)$$

$$RSQ = r^2 \quad (8)$$

Accuracy rates of training and testing were calculated in Equation (9);

$$The\ accuracy\ rate = (100 - \%MAE) \quad (9)$$

4. ANN modelling results

In this study, the data in Table 1 are used for the ANN model seen from Figure 2. The length of the whole data was 25 lines. First 5 lines of the data were separated for test. More than patch dimensions, the substrate specifications and U-slot dimensions are important on the bandwidth of the microstrip antenna [6, 23-25] so for the ANN model, L_s, W_s, $\varepsilon_r, h, t_L,$ and t_W are used as inputs, after the bandwidth was calculated as the network output.

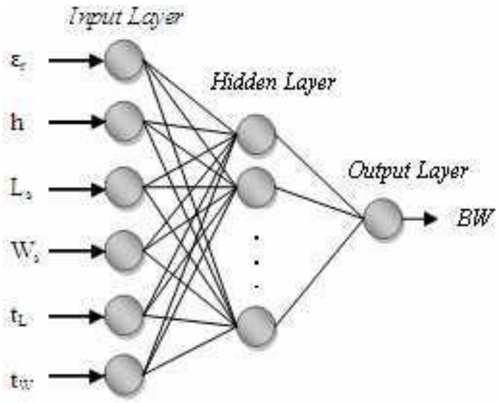

Figure 2. ANN structure used for modeling.

Consequently, the number of nodes for input ANN and output ANN were formed as 6 and 1, respectively. The developed ANN structure included one hidden layer. MLP feed forward back-propagation was used as an ANN structure.

The hidden layer node numbers of optimum ANN structure was found as 18, experimentally. For this hidden node, minimum training and test errors were obtained. In the training, first a scan process for finding the best hidden node number and best iteration number was run random search where the iteration number was adjusted from 500 to 10000 with 500 intervals and the hidden nodes number was adjusted from 3 to 30. After this process, the iteration number and node number of hidden layer was found to be 8000 and 18, respectively, while initial learning coefficient of the network as " = 0:9, initial momentum coefficient adjusting the learning speed as α = 0:7 was selected. ANN diagram was trained and tested with 5-fold cross validation methods under the best optimum structure determined by trials. The mean square errors of training and testing at the best ANN architecture were found to be %0.88 and %0.23, respectively. Correlation analysis was performed [18-25]. The results of this analysis of train and test phase were found to be r^2 = 0:94 and 0.97, respectively. The above given average error and average correlation values of testing and training phases versus iteration number were determined by the help of measured and simulated antenna bandwidths for U-slot rectangular microstrip antennas and developed ANN model outputs, the correlation between outputs of ANN and simulation outputs for testing and training then they were presented graphically in Figure 3, respectively. Rectangular microstrip antennas used as ANN test parameters and the obtained results are given in Table 1.

Table 1. Rectangular microstrip antennas ANN test parameters and results.

No.	$\in_r$	h	L_S	W_S	t_L	t_W	BW-Exp.	BW-ANN
1.	2.20	3.175	6.60	6.00	0.60	0.60	39.00	39.07
2.	2.20	3.175	9.30	12.00	0.80	0.80	15.00	14.51
3.	2.20	5.000	12.00	16.00	2.00	2.00	13.00	15.64
4.	2.20	6.350	23.30	25.90	2.30	2.30	13.50	13.97
5.	1.00	5.000	20.00	12.00	2.00	2.00	25.00	27.04
6.	1.00	5.000	18.00	10.00	2.00	2.00	28.00	26.87
7.	2.20	12.160	27.65	21.48	3.09	3.09	29.52	31.02
8.	2.35	12.160	39.54	26.04	4.42	4.42	21.36	21.27
9.	2.94	12.160	25.86	20.09	3.72	3.72	28.71	29.00
10.	3.00	12.160	26.15	20.31	2.93	2.93	29.21	28.74
11.	3.27	12.700	27.77	21.38	3.06	3.06	27.70	27.58
12.	3.48	12.500	32.83	25.51	3.67	3.67	21.40	21.61
13.	4.50	12.700	24.5	19.00	2.74	2.74	23.00	27.62
14.	6.00	12.700	22.47	17.30	2.50	2.5	23.26	23.11
15.	6.15	12.700	27.00	20.98	3.02	3.02	20.77	20.99
16.	9.80	8.000	17.50	13.16	1.96	1.96	39.58	39.58
17.	1.00	5.000	20.00	12.00	2.00	2.00	25.00	27.04
18.	2.33	6.400	18.00	14.00	2.00	2.00	2500.	22.27
19.	2.33	8.000	18.00	14.00	2.00	2.00	25.30	27.48
20.	2.32	8.000	18.00	14.00	2.00	2.00	25.30	25.73
21.	1.00	8.000	14.00	18.00	2.00	2.00	26.54	28.14
22.	1.00	5.000	19.50	12.0	2.10	2.10	32.40	27.73
23.	1.00	5.000	16.50	14.00	2.10	2.10	30.00	28.93
24.	1.00	26.924	82.17	68.58	10.16	8.89	47.00	44.51
25.	1.00	13.462	82.17	68.58	10.16	8.89	12.40	18.27

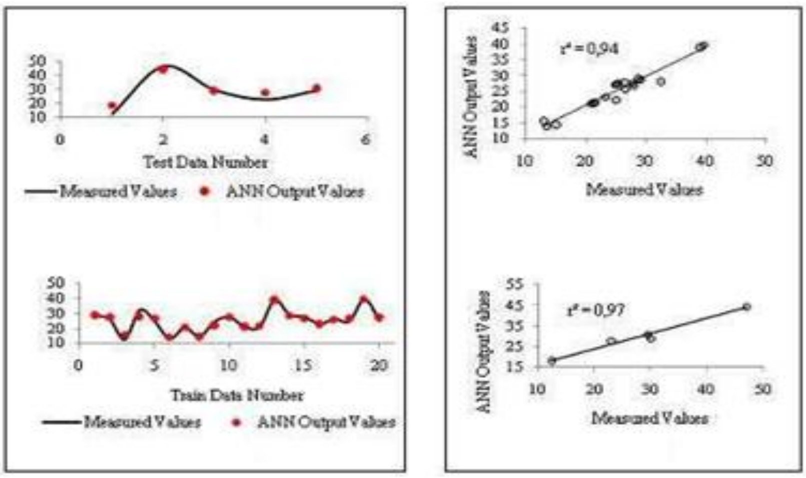

Figure 3. (a) ANN test output results comparison with simulation values. (b) ANN train output results comparison with simulation-measurement values. (c) Correlation between ANN output values and antenna bandwidth outputs for training. (d) Correlation between ANN output values and antenna bandwidths for test.

5. Conclusions

This paper is survey on the Rectangular micro strip patch antenna. Many techniques improve gain and bandwidth of the Micro strip Antenna. Due to this survey effect of disadvantages can be minimized. Array configuration can overcome the Low gain and power handling capacity. The feeding techniques also improve their performances. There are many simulation software are developed for micro strip antenna which make easy of designing in proper ,accurately and in automatic way with eliminating all complexity. In this study, bandwidth calculation of rectangular U-slot microstrip antennas are achieved by the help of an Artificial Neural Network model trained with GDX algorithm. In the training of neural network, K-fold cross-validation is used for test results to be more valuable. The measurement values obtained from experimental studies and the results of trained and tested ANN model are compatible with each other in great proportion. The accuracy ratios of training and testing stages in obtained optimum ANN were found to be 98.6% and 93.3%, respectively. These results show that the ANN network is studied successfully for calculation of the bandwidth values of rectangular U-slot microstrip antennas.

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