Efficient Neural Model of Microwave Patch Antennas

Zoran Stanković, Bratislav Milovanović, Marija Milijić

Abtract – **Modeling of patch antennas using multilayer perceptron neural network model (MLP) is presented in this paper. To achieve high accuracy, two neural networks are used for calculating resonant frequency f_r and minimum value of s_{11} parameter (s_{11min}). Both neural networks have the same four input parameters: patch antenna length L, patch antenna width W, depth of patch antenna slot l and width of patch antenna slot s, but they have different output: first neural network gives value of resonant frequency f_r and the second gives value of s_{11min} parameter.**

Keywords – **Neural network, patch antenna, modeling**

I. Introduction

The intense development of up-to-date wireless communication systems has led to widespread using of patch antennas [1]. Patch antennas have a lot of advantages then other traditional types of antennas (efficacy, compact physically realization and mechanical reliability). Requests concerning quality, performance and realization quickness of wireless communication systems dictate that tools for patch antenna modeling must be fast and failsafe.

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating substrate. Because such antennas have a very low profile, are mechanically rugged and can be conformable, they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. A typical patch antenna is shown in Figure 1. A patch antenna consists of a radiating patch of any planar geometry (e.g. circle, square, ellipse, ring and rectangle) on one side of a dielectric material substrate backed by a ground plane on the other side [2]. The patch is generally made of conducting material such as copper or gold [3]. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Generally, a substrate with a low dielectric constant (ε_r) is used (typically ~ 2.5), but in loss critical applications, Alumina (ε_r =10) must be used. Patch antennas are also relatively inexpensive to manufacture and design because of the simple 2-dimensional physical geometry. Their properties allow patch antennas to be used in many areas of communications (in wireless applications, as antenna in mobile phone, pager, etc., and in satellite communications) [4].

The authors are with the Faculty of Electronic Engineering, Aleksandra Medvedeva 14, Niš, Serbia and Montenegro,
E-mail: zoran@elfak.ni.ac.yu, batam@pogled.net, marijam@elfak.ni.ac.yu,

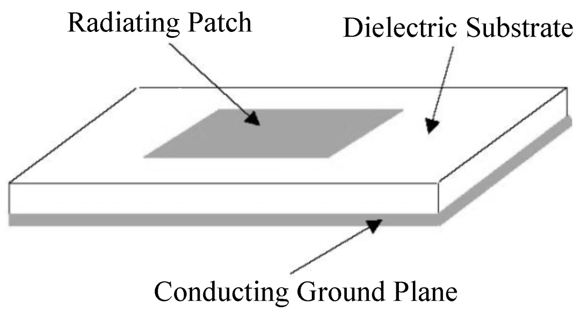

Fig. 1. Typical patch antenna

The most known method used for modeling of patch antennas is electromagnetic simulation. Although it gives models with high accuracy, it has some disadvantages. Its basic disadvantage is that electromagnetic simulation has high demands concerning the hardware resources necessary for its software implementation. The software implementation itself might be very complicated and faced with many difficulties. Also the time needed for numerical calculation when using an electromagnetic simulation could be unacceptably long.

Good alternative for overcoming all these problems is modeling of patch antennas using an artificial neural network model. Neural network model in these cases can be fast and accurate as detailed EM simulation method [5,6]. To improve accuracy of modeling of patch antennas using neural network model, two neural networks are used: one for modeling patch antenna resonant frequency f_r and second for modeling patch antenna s_{11min} parameter.

II. Neural Model of Patch Antenna

Multilayer perceptron (MLP) neural network is high-parallel and high-adaptive feed-forward structure that is consisted of mutually connected neurons with nonlinear activation functions in hidden layers [7,8,9]. Researching of MLP application in wireless communications has showed that this network is able to approximate highly nonlinear functions with satisfactory accuracy and high level of generalization. Using this structure there is no need of knowledge for the explicit functional connection between the output and input parameters. Architecture of the MLP neural model for modeling of patch antennas is presented in Fig.2. It consists of two neural networks: one for modeling patch antenna resonant frequency f_r and second for modeling patch s_{11min} parameter. Both neural networks consist of neurons grouped into the following layers: input layer, output layer and one or more hidden layers. The number of neurons in the hidden layers can be variable. The general symbol of this type of MLP neural model is MLPH-N_1-N_2-...-N_H, where H is the number of hidden layers, and N_i is the number of neurons in the i-th hidden layer.

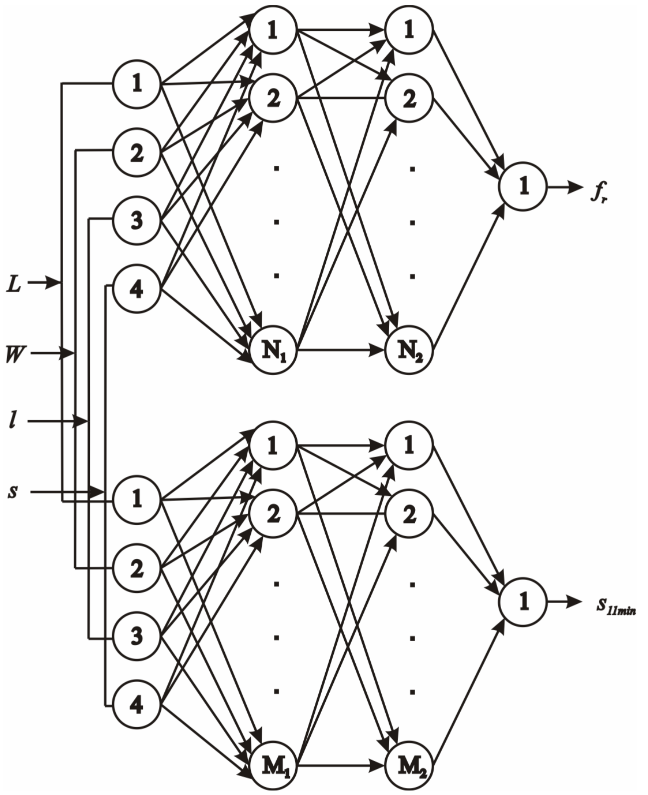

Fig. 2. MLP neural model for modeling of patch antennas

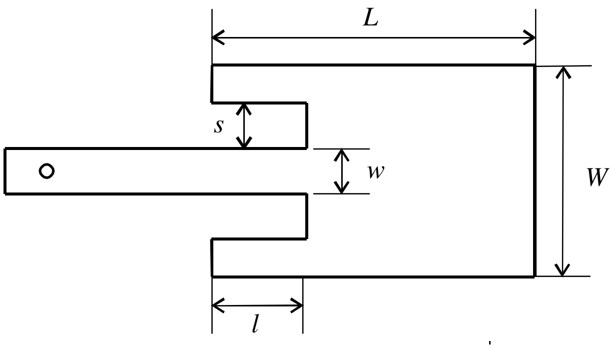

Fig. 3. Slotted patch antenna

Each neural network has been trained separately. Their numbers of neurons in hidden layers and their transfer functions in hidden and output layers have been changeably to achieve a goal of minimum error.

First neural network has been trained to calculate value of resonant frequency f_r. Input vector $\mathbf{x}=[L,W,l,s]^T$ is presented to the input layer and fed through the network that then yields the output $\mathbf{y}=[f_r]$. Therefore, the neural model is given by $\mathbf{y}=y(\mathbf{x},W)$ where W is a set of connection weight matrices among neurons [7,8,9]. The vector of l-th hidden layer outputs is:

$$\mathbf{y}_l=\mathrm{F}(\mathbf{w}_l\mathbf{y}_{l-1}+\mathbf{b}_l) \quad (1)$$

where $\mathbf{y}_l$ is a $N_l \times 1$ vector of l-th hidden layer outputs, $\mathbf{y}_{l-1}$ is a $N_{l-1} \times 1$ vector of $(l$-1)-th hidden layer outputs, $\mathbf{w}_l$ is a $N_l \times N_{l-1}$ connection weight matrix among (l-1)-th and l-th hidden layer neurons, and $\mathbf{b}_l$ is a vector containing biases of l-th hidden layer neurons. In the above notation $\mathbf{y}_0$ represents outputs of the buffered input layer $\mathbf{y}_0 = \mathbf{x}$. F is the transfer function of hidden layer neurons and F was changeable during training process to obtain network with minimum error. All neurons from the last hidden layer H are connected with the neuron of the output layer. Since the transfer function of output layer is linear, the output of the network is:

$$f_r=\mathbf{w}_o\mathbf{y}_\mathrm{H}$$

where $\mathbf{w}_o$ is a $1 \times N_H$ connection weight matrix among the H-th hidden layer neurons and output layer neuron (Fig. 2).

Table 1. Test results of neural network for patch antenna f_r modeling

Layer-Transfer function and number of neurons			WCE	ACE	p^{rom}
Hidden		Output			
1	2				
Tansig-9	Tansig-9	Purelin-1	9.88%	0.88%	0.98
Logsig-10	Logsig-5	Purelin-1	14.5%	0.96%	0.99
Logsig-9	Tansig-9	Purelin-1	19.11%	0.86%	0.99
Losig-10	Tansig-8	Satlins-1	19.21%	0.89	0.99
Tansig-15	Logsig-15	Purelin-1	23.1%	0.9%	0.98

Table 1. Test results of neural network for patch antenna s_{11min} parameter modeling

Layer-Transfer function and number of neurons			WCE	ACE	p^{rom}
Hidden		Output			
1	2				
Tansig-15	Tansig-10	Satlin-1	11.75%	3.45%	0.96
Logsig-10	Logsig-5	Satlin-1	19.9%	3.72%	0.96
Tansig-14	Tansig-10	Poslin-1	17.32%	4.54%	0.95
Logsig-9	Logsig-9	Poslin-1	24.6%	3.38%	0.96
Tansig-10	Tansig-8	Purelin-1	21.91%	3.68%	0.96

Output from second neural network is s_{11min} parameter of patch antenna. This network has the same input as the first network. During training it must approximate function $\mathbf{y}=y(\mathbf{x},W)$, where $\mathbf{x}=[L,W,s,l]^T$ is model input, $\mathbf{y}=[s_{11min}]^T$ model output and W is a set of connection weight matrices among neurons. Also, the second neural network is feed-forward and it has the same principles and formulas of connections among neurons and layers. Its transfer functions were changeable during training process, too. The output of the second network is:

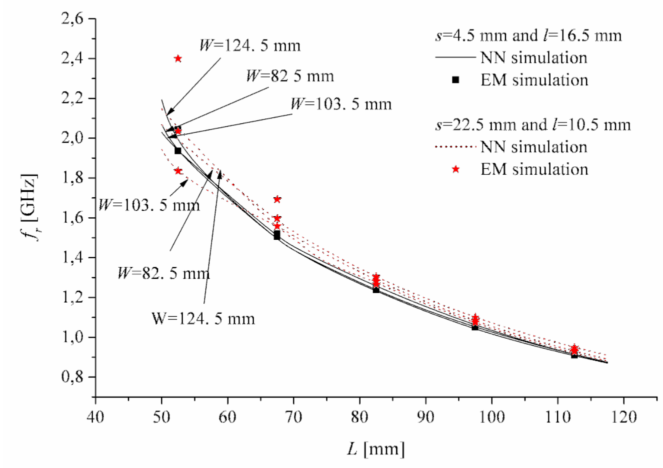

Fig. 4. f_r in the function of parameter L

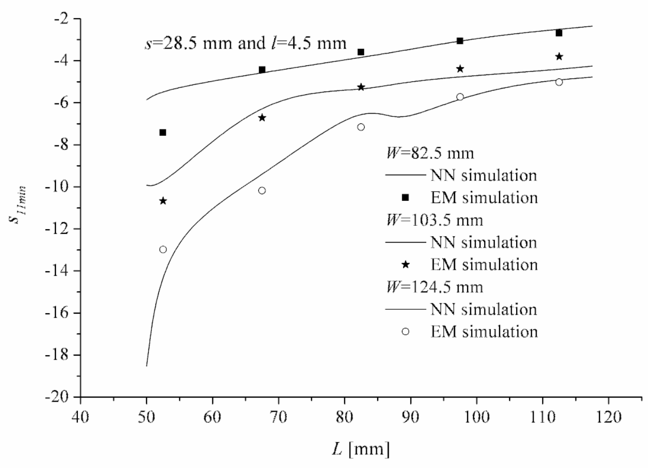

Fig. 6. s_{11min} in the function of parameter L

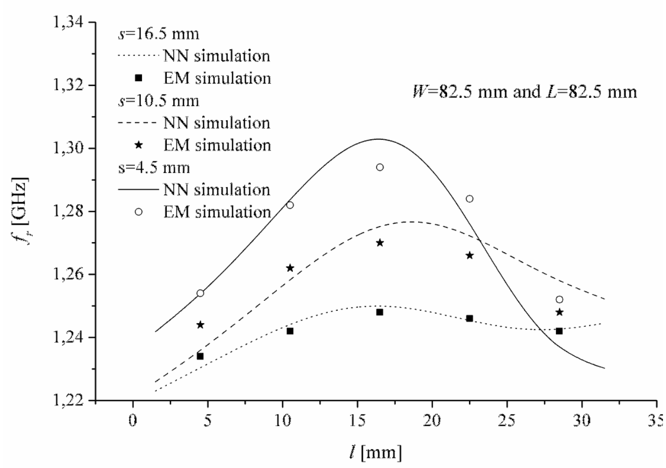

Fig. 5. f_r in the function of parameter l

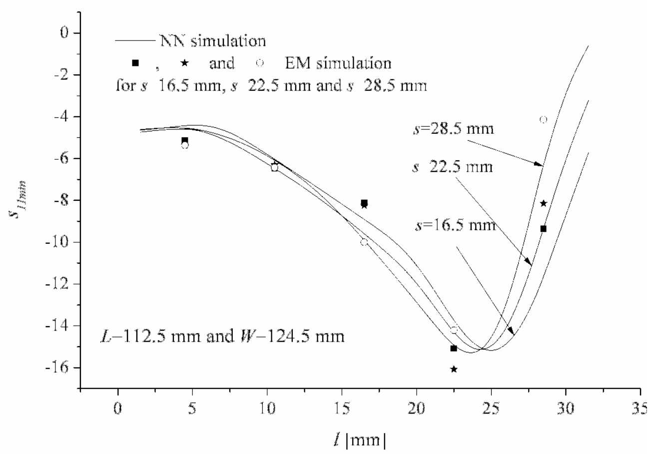

Fig. 7. s_{11min} in the function of parameter l

$$s_{11min}=\mathbf{w}_o\mathbf{y}_H$$

where $\mathbf{w}_o$ is a $1 \times N_H$ connection weight matrix among the H-th hidden layer neurons and output layer neuron (Fig.2).

This neural model is used for slotted patch antenna, which is shown in Figure 3. Antenna is constructed of substrate with fallowing features: relative dielectric constant ε_r = 2.17, thickness h = 0.508 mm, conductor thickness T = 0.017 mm. Electromagnetic simulation of slotted patch antenna using HFSS 9.0 software, for constant parameter w =0.5 mm and for variable parameter L, W, l and s, has given values of resonant frequency f_r and s_{11min} parameter. Electromagnetic simulation results have been used as input for training neural model whose output is values of parameters f_r and s_{11min} parameter.

III. Test Results

Each neural network is tested to check obtained generalization level. The test of both neural networks has been done using uniform test group consisted of samples which have not been used in training. To quantify models' accuracy an average test error (*ACE* [%]), worst-case error (*WCE* [%]), and Pearson Product-Moment correlation coefficient (r^{PPM}) between the referent and the modeled data were calculated. In Table 1 and Table 2., test results for the both neural networks are presented. In both cases, five best models are shown.

IV. Simulation Results

Neural models M4-9-9 (transfer functions: Tansig, Tansig, Purelin) and M4-15-10 (transfer functions: Tansig, Tansig, Satlin) have the best testing results and they are used for checking obtained generalization level. First neural models M4-9-9 has been trained for modeling patch antenna resonant frequency f_r and it is used for representation resonant frequency f_r as function of antenna parameters L and l and for comparison these results with results obtained by EM simulation (Figure 4. and Figure 5.). These figures show the quality of neural models M4-9-9 training which is very satisfying. Also, they represent how resonant frequency f_r depends on antenna parameters L and l (when other parameters are constant).

Also, neural models M4-15-10, trained for modeling patch antenna s_{11min} parameter, is used for verifying its genera-

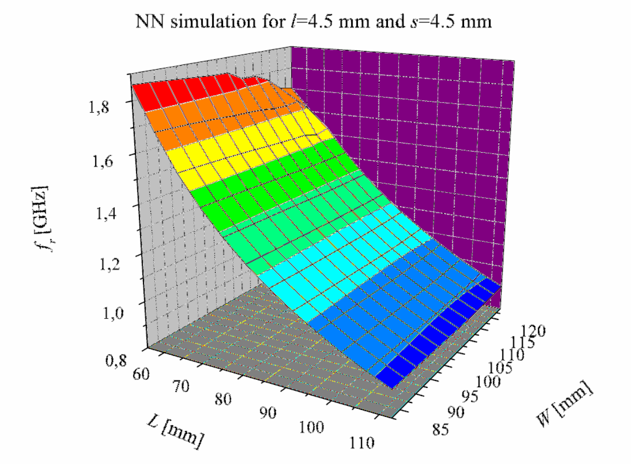

Fig. 8. f_r in the function of parameters L and W

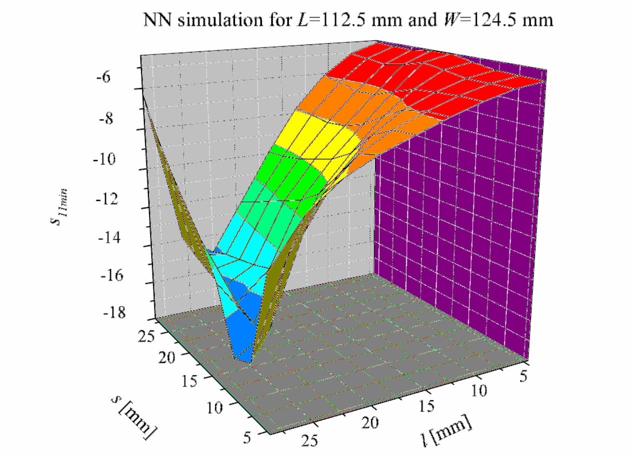

Fig. 9. s_{11min} in the function of parameters l and s

lization level. Parameter s_{11min} is shown as function of antenna parameters L and l and these results have been compared with values obtained by EM simulation (Figure 6. and Figure 7.). As these figures show, neural models M4-15-10 is correct and it can be used for modeling patch antenna s_{11min} parameter very correctly.

Both neural networks have satisfying precision, but they improve patch antenna modeling with very great speed of work. In Figure 8., the dependence f_r on parameter L and W, when l and s parameters are constant, is shown. This dependence is shown using 315 values of f_r obtained by NN simulation for less then 1 seconds. If we use EM simulation to obtain the same number of f_r values, we will do it for 2 hours. Also, Figure 9. represents s_{11min} as function of parameters s and l when W and L are constant values. If we use EM simulation to obtain 441 values of s_{11min} parameter, we will finish it after 3 hours of simulation. NN simulation obtains 441 needed values of s_{11min} parameter for 1 second. For these reasons, NN simulation is better alternative in applications where simulation has to be finished in certain period of time.

V. Conclusion

Software including EM simulation is the most used method for modeling of patch antenna. Its accuracy is good, although it has many limitations (the simulation process is complicated and slow, there is the problem of hardware resources necessary for its software implementation). Good alternative is to use neural network modeling. MLP model is easy to be developed, has high simulation speed and satisfying accuracy.

Further usage of this neural model of patch antennas will be as base of software for modeling patch antennas. It will represent software part for numerical calculation and software interface will be part which will respond on user requests.

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