Neural Network Approach in Modeling Microwave Slotted Patch Antennas

Bratislav Milovanović, Marija Milijić, Zoran Stanković

Abstract – **This paper presents a neural model based on multi-layer perceptrons (MLP) network for modeling slotted patch antennas. Neural model were trained to calculate accurately the resonant frequency *f* and the minimum value of S_{11} parameter (S_{11min}). Besides dimension parameters: antenna patch length *L*, antenna patch width *W*, deep of antenna patch slot *s* and length of antenna patch slot *l*, neural network relates and substrate layer height *h*. The developed neural model speeds up the process of collecting results by replacing repeated EM simulations and retains good accuracy compared with the MoM modeling.**

Keywords - **slotted patch antenna, neural network**

I. INTRODUCTION

Modern communication systems, from wireless to space communications, require compact and light weight components. One important component is the antenna, which, in addition, is required to have sufficiently high gain, wide bandwidth, high efficiency and to be easy to fabricate. Printed antennas are commonly used in these applications, since they inherently have low profile and low weight apart from having a low fabrication cost. They, thanks to their planar geometry, are usually integrated in devices mounted on a platform (for example in a mobile telephone).

Microstrip patch antenna is the most common form of printed antennas [1]. Due to its planar configuration and ease of integration with microstrip technology, it has been heavily studied and is often used as elements for an array. Consider the microstrip antenna shown in Figure 1, fed by a microstrip transmission line. The patch is of length *L*, width *W* with slot of deep *s* and length *l*. It sits on top of a substrate of thickness *h* with permittivity ε_r. Typically the height *h* is much smaller than the wavelength of operation. A substrate with a low dielectric constant (ε_r) is used (typically ~ 2.5), but in loss critical applications, greater dielectric constant (ε_r =10) must be used.

The most known method used for modeling patch antennas is the electromagnetic simulation. Although it is very correct process, it has some disadvantages which can not satisfy requirements of communication systems designing under some circumstances. 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 by electromagnetic simulation could be unacceptably long.

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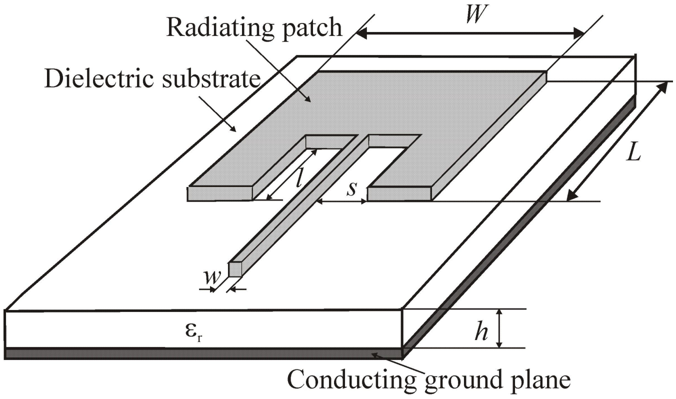

Fig. 1 Slotted patch antenna

The method of moments (MoM) is a very popular algorithm of computer electromagnetic calculations. It is widely used for antenna simulations and electromagnetic wave scattering analysis due to its good accuracy. The main disadvantages of the MoM is demand to solve a large number of time-consuming complex electromagnetic equations.

In this paper, the modeling patch antenna using neural networks is studied as an alternative method to detailed EM modeling. The previous researching, concerning the modeling of patch antennas have showed that the neural network models can have satisfactory accuracy similar as MoM but also can have higher simulation speed then EM simulations [2-5]. In this researching, it is shown that neural network could be very successfully for slotted patch antenna modeling considering dimension parameters: antenna patch length *L*, antenna patch width *W*, deep of antenna patch slot *s* and length of antenna patch slot *l*. As further study of modeling patch antennas, the authors developed in this paper neural network which considers and substrate layer height *h* influences on the resonant frequency f_r and the minimum value of S_{11} parameter (S_{11min}).

II. MAIN CONCEPT OF NEURAL NETWORKS

Owing to the capability of a functional dependence's modeling exclusively on the basis of input data, Multilayer Perceptron Network (MLP) is a type of neural network that can be successfully applied in the modeling of slotted patch antennas [6].

Neural networks, created in imitation of biological nervous systems, consist of connected cells (neurons) which parallel process data [7]. Connections between neural networks cells feature with weights. During process of training neural network for special problem, values of weights between neural network neurons change to give expecting output for specified input. Such type of training is called supervised training and it is used for training neural network for modeling slotted patch antennas. Proposed neural multi-layers network for modeling patch antennas has four layers (Fig. 2). Outputs from all neurons of previous layer are input in every neuron in next layer whereas neurons in same layer are not connected together. Input data vector is run into input layer whose number of neurons is equal to input vector dimension (the number of input data). The latest layer of neural network is output layer and its neurons give output of neural network. Other neurons, which are not connected with input or output links, are hidden neurons. Signals through neural network runs in one direction, from input to output, and this network is example of feed forward network [7].

MLP neural network for modeling slotted patch antennas consists of input, two hidden and output layers. The number of input layer neuron is equal to number of antenna parameters that determine modeling. In this application, there are five input parameters: antenna patch length L, antenna patch width W, deep of antenna patch slot s, length of antenna patch slot l and substrate layer height h. The number of hidden layer neurons is variable during training process and output layer has two neurons that give resonant frequency f_r and S_{11min} parameter. The MLP network models the function:

$$[f_r, S_{11\min}] = f\ (L, W, l, s, h) \quad (1)$$

The activation functions of the hidden layers are sigmoid, while the neurons of the output layers have linear activation functions. The neural networks were trained using Levenberg-Marquardt method with 10^{-3} performance goal. The notation of MLP models is MLPn-l_1-l_2-…-l_{n-2} where n represents layer number and l_1-l_2-…-l_{n-2} are the numbers of neurons of its each hidden layer.

The values of resonant frequency fr and S_{11min} parameter, necessary for the training and the test MLP neural networks, were obtained by ADS 2006 software. This software uses method of moments to calculate S_{11min} parameter for certain frequency f of slotted patch antenna with specific dimension. Training and test sets consist of only resonant frequency f_r defined by minimum value of S_{11} parameters for specific slotted patch antenna.

Patch antenna, modeled in this paper, has a substrate with dielectric constant ε_r=2.17. The width of fed line w depends on substrate layer height h and its range is [0.5 mm, 3.5 mm][8]. The other antenna parameters are changeable. In the training set with 3456 samples five input parameters have following range: 45 mm≤L≤120 mm, 70.5 mm≤W≤133.5 mm, 1.5 mm≤l≤31.5 mm, 1.5 mm≤s≤31.5 mm and 0.208 mm≤h≤1.108 mm.

III. TEST RESULTS

The test set contained 405 samples that have not been used in training process. Test results of successfully trained neural networks are presented in the Table I together with the average test error (*ATE*), the worst case error (*WCE)* and the Pearson Product-Moment correlation coefficient (r^{PPM}). The minimum of worst test error and the maximum value of Pearson Product-Moment correlation coefficient represent the basic criterion for selection the best MLP network. Selected neural model is MLP4-12-6.

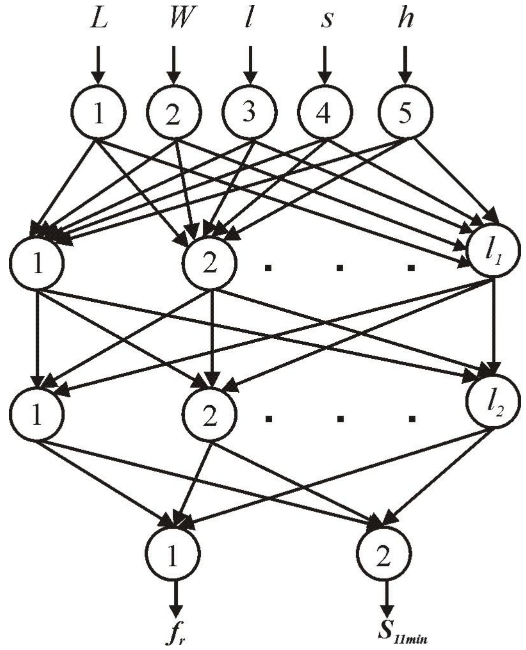

Fig. 2 MLP neural network for modeling slotted patch antenna

TABLE I TEST RESULTS

MLP model	*WCE*[%]	*ACE*[%]	r^{ppm}
MLP4-12-6	43.09	2.59	0.93
MLP4-15-10	45.68	2.54	0.93
MLP4-20-10	43.12	2.84	0.92
MLP4-16-8	46.74	2.90	0.92
MLP4-9-9	48.60	2.68	0.92
MLP4-20-15	49.27	2.80	0.91
MLP4-18-16	48.01	2.87	0.91
MLP4-14-12	46.09	2.93	0.90

IV. SIMULATION RESULTS

Beside its best test results, generalization level of MLP4-12-6 model should be checked as its advantages over previous methods for modeling slotted patch antenna. First, dependence of antenna parameter S_{11min} on patch length L for different values of substrate layer height h obtained by MLP4-12-6 is compared with MoM simulation results in Fig. 3. This figure shows the satisfying accuracy of MLP model compared with MoM simulation results. The simular conclusion can be done in Fig. 4. that shows how resonant frequency f_r depends on antenna patch parameters L for different values of substrate layer height h. Results obtained by MLP model very good agree with results of MoM simulation.

Further, preposed MLP model is used for representing both parameter S_{11min} and resonant frequency f_r as function of

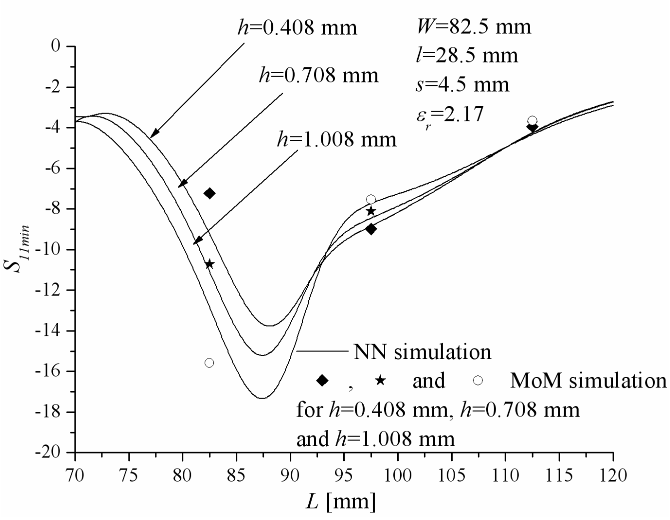

Fig. 3 S_{11min} parameter vs. antenna patch length L for different values of substrate layer height h

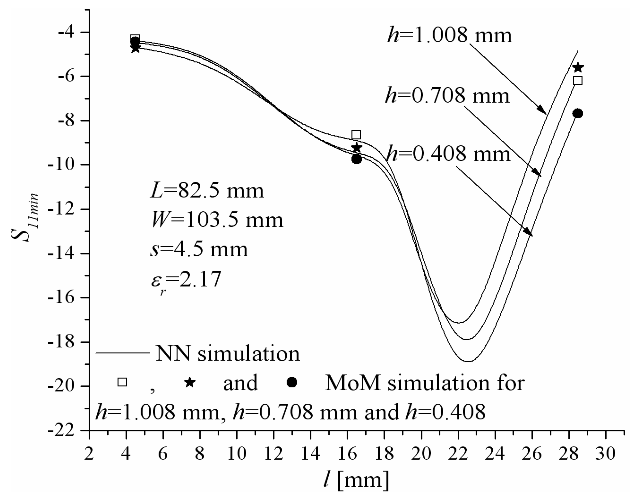

Fig. 5 S_{11min} parameter vs. antenna patch slot length l for different values of substrate layer height h

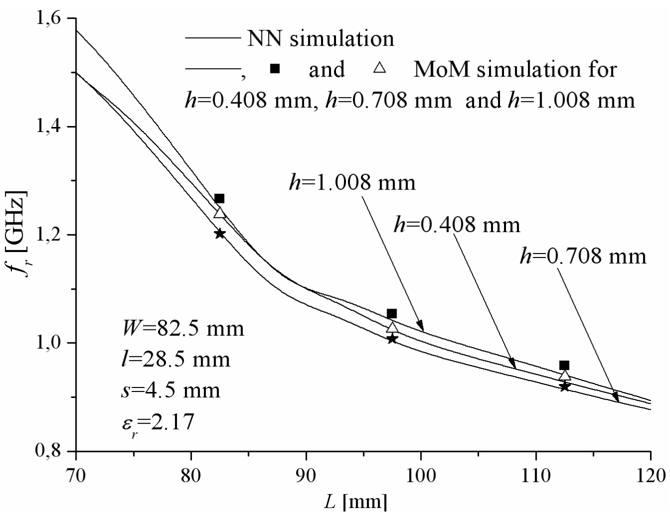

Fig. 4 Resonant frequency f_r vs. antenna patch length L for different values of substrate layer height h

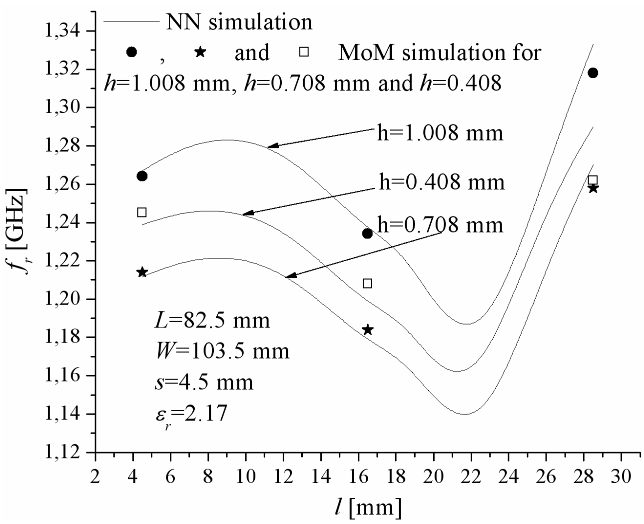

Fig. 6 Resonant frequency f_r vs. antenna patch slot length l for different values of substrate layer height h

antenna parameters l for different values of substrate layer height h and these results have been compared with values obtained by MoM simulation (Fig. 5. and Fig. 6.).

As all these figures show, MLP4-12-6 model is correct and it can be used for modeling patch antenna S_{11min} parameter and resonant frequency f_r with acceptable accuracy compared with MoM simulation used in ADS 2006 software.

Added to its accuracy, MLP model improves patch antenna modeling with very great speed of work. Fig. 7. shows the dependence f_r on parameter L and W, when h, l and s parameters are constant. This dependence is presented using 352 values of f_r obtained by NN simulation for 2 seconds. If we use MoM simulation in ADS 2006 software to obtain the same number of f_r values, we will do it for one day. Also, Fig. 8. represents S_{11min} as function of parameters s and l when h, W and L are constant values. MoM simulation from ADS 2006 sofware, obtains 256 values of S_{11min} parameter for 20 hours. NN simulation obtains needed 256 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

Patch antennas are increasing in popularity for use in different communication systems due their numerous advantages. Therefore, requests concerning quality, performance and realization quickness of wireless communication systems dictate that tools for patch antenna modeling must be fast and failsafe. Detailed EM modeling based on numerical techniques is the most often used method for modeling patch antennas. It features with great accuracy. But, it has many limitations. First limitation of

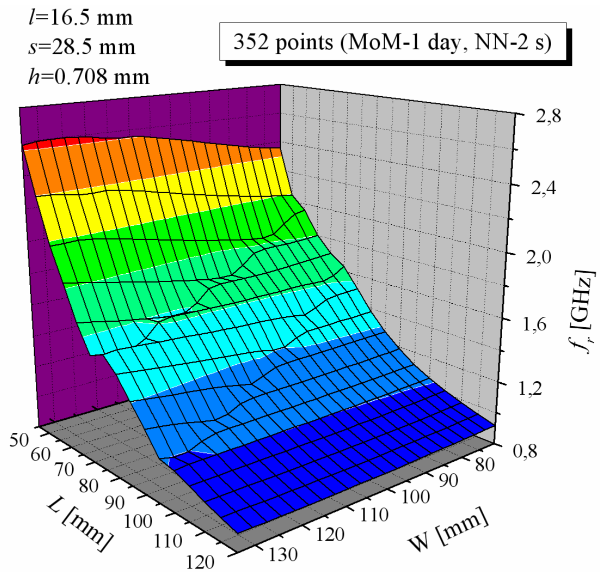

Figure 7 f_r vs. parameters L and W with constant h, l and s parameters

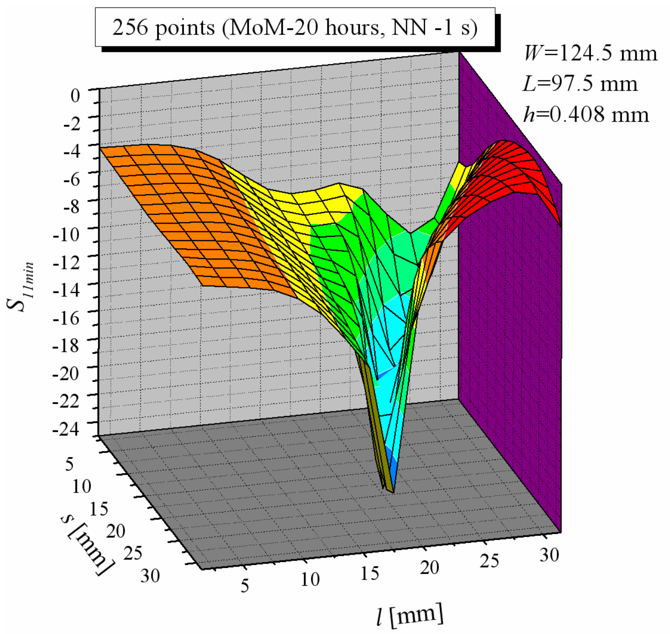

Figure 8 S_{11min} vs. parameters l and s with constant h, L and W parameters

EM methods is very strong hardware platform request. Also, its numerical calculations are done for a long period of time.

Neural model presented in this paper, thanks to its features, can surpass these problems. After successfully finished training, its accuracy is not significantly less then accuracy of detailed EM modeling, although it is much faster. It considers five parameters of patch antenna, four dimensional parameter - antenna patch length L, antenna patch width W, deep of antenna patch slot s and length of antenna patch slot l and one which features substrate layer - its height h. The great speed of neural models can give good base for introducing active models in the optimization process of planar structures.

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