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Software for Microwave Slotted Patch Antenna Design Based on Hybrid Empirical-Neural Model

Bratislav Milovanović, Zoran Stanković, Marija Milijić and Maja Sarevska

Abstract-**This paper presents a software "*MW Patch Antenna Design 2.0*" intended for modeling microwave slotted patch antennas. This software uses Hybrid Empirical-Neural Model (HEN) which, unlike the models based on a classical multi-layer perceptron (MLP) network, includes an existing partial knowledge about the resonant frequency behavior of patch antenna, yielding more accurate determination of the resonant frequencies f_r and the minimum value of S_{11} parameter (S_{11min}).**

Keywords-**Neural network, patch antenna, modeling, software**

I. Introduction

A microstrip patch antenna provides a great advantage over traditional antennas such as efficacy, compact physically realization and mechanical reliability. This narrowband, wide-beam antenna is lightweight, inexpensive and conformable. Due its numerous advantages, it is often used in wireless communication systems, mobile communications and many microwave applications [1]. Therefore, the tools for patch antenna modeling are dictated to be fast and failsafe.

The typical patch antenna is shown in Figure 1. It 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. The patch is generally made of conducting material such as copper or gold [2]. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. 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 [3].

The most known method used for modeling of patch antennas is electromagnetic simulation. Although it is very correct and effective process, it has some disadvantages which can not satisfy requirements of communication systems designing. Its basic disadvantage is that electromagnetic stimulation 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 which can be fast and accurate as detailed EM simulation method [4,5,6]. But, the main disadvantage of MLP models is a need for providing a large set of training data, that could be difficult and time-consuming process [7].

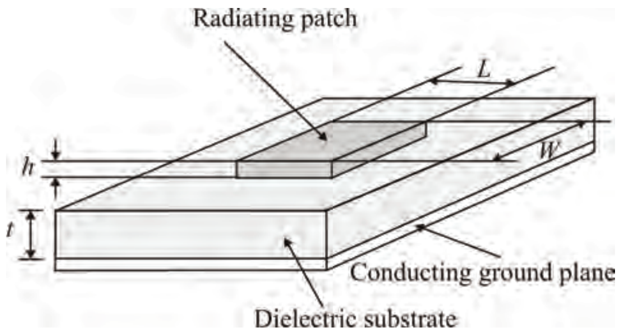


Figure 1. Typical patch antenna

Many earlier researches modeled only the resonant frequency of patch antennas [8,9,10], while they omitted modeling of patch antennas S_{11min} parameters which represents patch antenna losses. Hybrid Empirical-Neural (HEN) model of patch antennas, which incorporates knowledge about both the behavior of the resonant frequency and the behavior of S_{11min} parameters, needs smaller set of training data then MLP model for achieving satisfying model accuracy [11]. This HEN has six input parameters: patch antenna length L, patch antenna width W, depth of patch antenna slot l, width of patch antenna slot s, the resonant frequency f_r^e determined by approximate model and S^e_{11min} parameter determined by specially developed MLP model and it gives value of resonant frequency f_r and value of S_{11min} parameter of patch antenna. It is used for software "MW Patch Antenna Design 2.0" developing that calculates resonant frequency f_r and S_{11min} parameter of patch antenna.

II. Knowledge About Patch Antenna Resonant Frequency

Slotted patch antenna, whose HEN model is presented in this paper, is shown in Fig. 2. 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. Detailed earlier research [4,5,6] has shown that the resonant frequency f_r of patch antenna depends on patch antenna length L, patch antenna width W, depth of patch antenna slot l and width of patch antenna slot s for constant parameter w=0.5 mm:

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

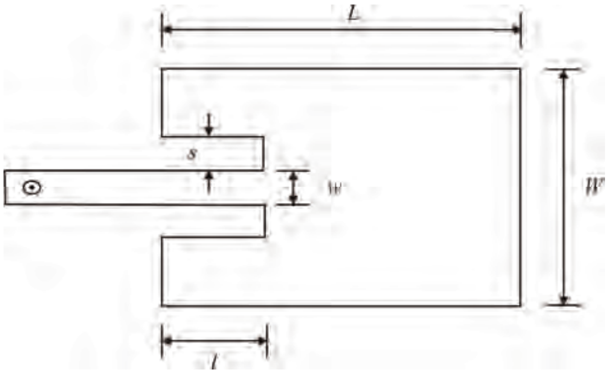


Fig. 2. Slotted patch antenna

$$f_r = f(L, W, l, s) \tag{1}$$

Also, the resonant frequency of a square-patch antenna in its dominant mode can be calculated using equation given by Wolf and Knoppik [8]:

$$f_r = \frac{c}{2L_{eff}\sqrt{\varepsilon_{dyn}}} \tag{2}$$

where c is the velocity of light in free-space, L_{eff} is the effective patch length:

$$L_{eff} = L + \Delta L \tag{3}$$

where ΔL is given as:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{4}$$

ε_{dyn} is the dynamic dielectric constant considering the fringing field effects:

$$\varepsilon_{dyn} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{5}$$

The resonant frequency f_r of a square-patch antenna given in analytical form (2) represents a partial semi-empirical knowledge from the problem domain implemented in the structure of HEN model whose architecture will be exposed further in this paper.

III. Hybrid Empirical-Neural Model of Patch Antenna

Hybrid Empirical-Neural Model of patch antenna appears as integration of the patch antenna approximate model as empirical knowledge holder, MLP network for calculating the value of S_{11min} parameter of patch antenna and MLP network. The basic idea in HEN model realization is that the empirical model and MLP network for calculating the value of S_{11min} parameter with corresponding connection to the neural network provides higher generalization and extrapolation capabilities of the network [7]. This is achieved by presenting extra information about the problem at the input of the network. According to that, architecture of HEN model for slotted patch antenna design is presented in Fig.3. Approximate model determines the resonant frequency f_r^e using equation (2). MLP network for calculating the value of S_{11min} parameter has been trained to give approximate S^e_{11min} value. The output from the approximate model, f_r^e, and the output from MLP network for calculating the value of S_{11min} parameter, S^e_{11min}, are brought to MLP as additional inputs. According to this, MLP of the HEN model is given by **y**=y(**x**,**w**), where **w** is a connection weight matrix among neurons [7,9], **x**=$[L,W,l,s,f_r^e,S^e_{11min}]^T$ is the input vector, and output vector is **y**=$[f_r,S_{11min}]$. During the training, network weight matrix **w** have to be adjusted in order to make the total main squared error E(**w**) between the desired outputs and the actual outputs from MLP network, lower than the prescribed value E_c [7]. Adjustment of the network parameters is determined by the chosen training algorithm. General symbol for this HEN model is HENH-$N1$-…-N_l-…-N_H where H is the total number of layers of neurons and N_i is the number of neurons in the i-th hidden layer. Activation functions of the hidden layers are sigmoid [7], while the output layer has linear activation function.

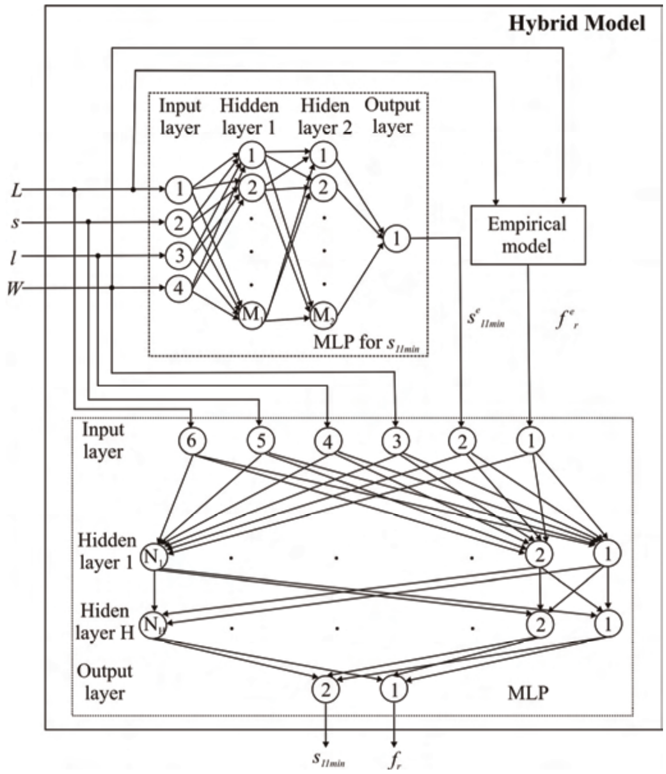


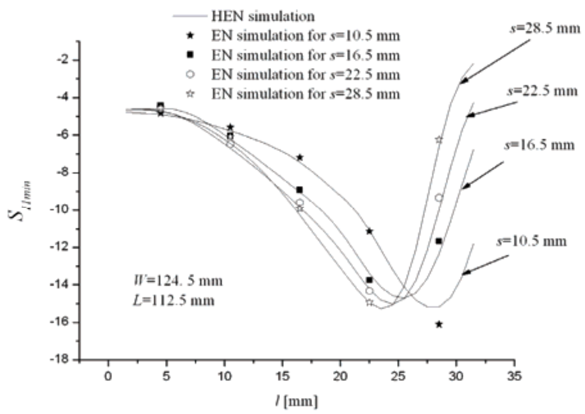
Fig. 3. Hybrid model of patch antenna

IV. Modeling Examples

HEN model is trained for calculation resonant frequency f_r and S_{11min} parameter of patch antenna. It is done in the wider range of input parameters: 52.5 mm ≤ L ≤ 112.5 mm, 4.5 mm

Table I TESTING RESULTS FOR HYBRID MODEL OF PATCH ANTENNA

Neural model	*WCE*	*ACE*	r^{PPM}
HEN4-4-2	17.28	2.05	0.97
HEN4-3-3	20.21	2.14	0.96
HEN4-2-2	21.20	2.09	0.97
HEN4-3-2	21.62	2.18	0.97
HEN4-2-4	22.02	2.14	0.96
HEN4-2-3	22.03	2.10	0.97
HEN4-3-4	22.47	2.24	0.96
HEN4-2-5	23.32	2.13	0.96



Slika 4 S_{11min} vs. parameters l

≤ s ≤ 28.5 mm, 4.5 mm ≤ l≤ 28.5 mm and 82.5 mm ≤ W≤ 112.5 mm. A training set of 375 samples has been obtained by electromagnetic simulation using HFSS 9.0 software.

Testing of the HEN model is done using testing data set (128 samples) that is not used in training process. The testing results for eight HEN models with the lowest average testing error (average test error (ACE [%]), worst-case error (WCE [%]) and Pearson Product-Moment correlation coefficient (r^{PPM})) are shown in TABLE I. Compared to the testing results of classical MLP model [6], it can see that the best HEN model is more accurate then the best MLP model, which vindicates using HEN model for patch antennas.

H4-4-2 model has the best testing results and it is used for checking obtained generalization level. First, it is used for representation parameter S_{11min} as function of antenna parameters l and these results have been compared with values obtained by EM simulation (Fig. 4.). As this figure shows, H4-4-2 model is correct and it can be used for modeling patch antenna S_{11min} parameter with acceptable accuracy.

This HEN architecture improves patch antenna modeling with very great speed of work. In Fig. 5., the dependence f_r on parameter L and W, when l and s parameters are constant, is shown. This dependence is shown using 900 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 1 hour. Also, Fig. 6. represents S_{11min} as function of parameters s and l when W and L are constant values. If we use EM simulation to obtain 378000 values of S_{11min} parameter, we will finish it after 20 days of simulation. NN simulation obtains 378000 needed values of S_{11min} parameter

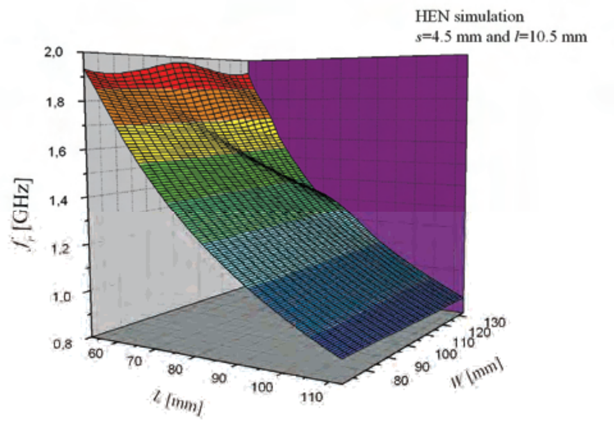


Fig. 5. f_r vs. parameters L and W

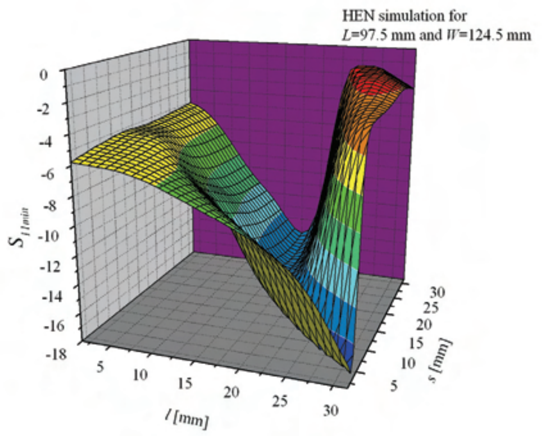


Fig. 6. S_{11min} vs. parameters l and s

for 2 second. For these reasons, NN simulation is better alternative in applications where simulation has to be finished in certain period of time.

V. MW PATCH ANTENNA DESIGN 2.0

Software module "MW Patch Antenna Design 2.0", whose code is written in Visual C++ programming language, uses HEN model for microwave slotted patch antennas design. Range of input parameters is limited by the range of parameters from training process. When user inputs parameters, the values of resonant frequency f_r and S_{11min} parameter are calculated for the patch antenna with these dimensions. This model works with great speed, e.g. the calculating resonant frequency f_r and S_{11min} parameter is done for less then 1 second. Also, it offers the possibility of optimization. It means that user do not have to input all antenna parameters (Fig. 7). The user can input one, two, three or no one parameters and this software module can calculate the values of resonant frequency f_r and antenna parameters when S_{11min} parameter is minimal, i.e. when antenna has minimal losses. Likewise, the range of resonant frequency f_r can be chosen. As a help to the user, the range of resonant frequency f_r is shown for the input antenna

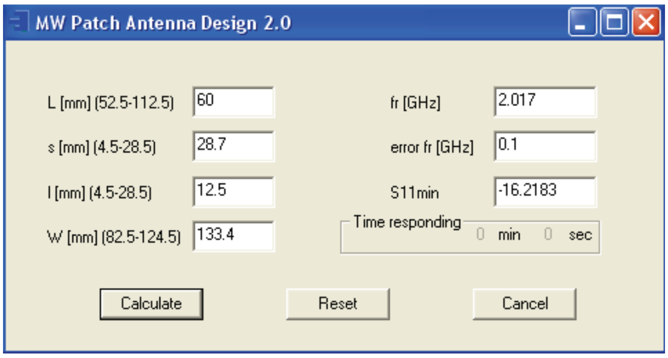


Fig. 7 Software MW Patch Antenna Design 2.0

parameters. If some antenna parameters are input, they are considered as constants and the other parameters values are looked for to obtain minimal value of S_{11min} parameter. The algorithm of this software is shown in Fig. 8. It calculates antennas parameters with accuracy of 10^{-1} mm while the accuracy of EM simulation is 100 mm. The optimization process has two phases. The first, which finds the approximate minimum of function $S_{11min} = \mathbf{g}(L,s,l,W)$, has accuracy of 100 mm. The second finds the real minimum of function **g** and its accuracy is 10^{-1} mm.

VI. Conclusion

EM simulation is the most used method for modeling of patch antenna. Despite its good accuracy, it has many limitations (the complicated, slow simulation process, high demands concerning the 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 if its training set is large enough. But, in cases when the training set is too small for the acceptable MLP model accuracy, the HEN model retains accurate modeling by incorporating existing knowledge for problem domain while it keeps the same simulation speed. This can be main advantage of using HEN model instead MLP models for microwave patch antennas. This HEN model is used to develope software module "MW Patch Antenna Design 2.0", which is high qualitative, fast and accurate programme and which can satisfy the user's requests.

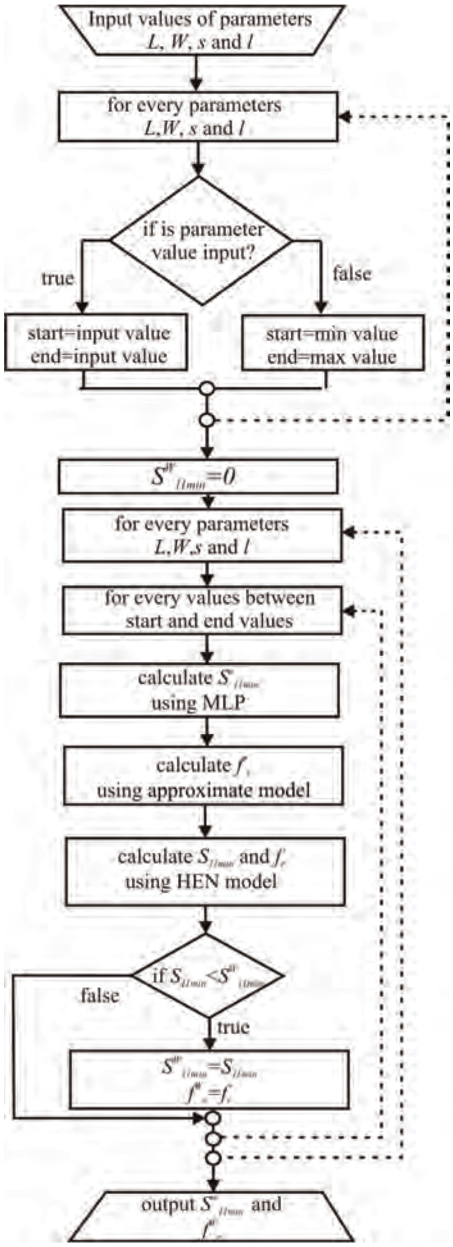


Fig. 8 The optimization process

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