FAST ACCURATE ANALYSIS AND MODELING OF MULTI-ANTENNA SYSTEMS IN THE [1.75-3.65 GHz] FREQUENCY BAND

Nazih HAMDIKEN[1], Rafik ADDACI[2], Tarek FORTAKI[3], Rodica STRUNGARU[4], Mihaela UNGUREANU[5]

In this paper, a model allowing to analyze multi-antenna systems based on two planar inverted F antennas (PIFA) on a limited printed circuit board (PCB) is proposed. It uses the neutralization line as isolation technique and artificial neural network (ANN) as modeling method. This model allows us to obtain the desired performance in terms of resonant frequency, bandwidth and isolation level with an important time gain compared to other software simulation.

Keywords: Antenna modeling, multi-antenna systems, Planar Inverted F Antenna (PIFA), Artificial Neural Network (ANN)

1. Introduction

Multi-antenna systems have attracted considerable interest of researchers [1-2]. These systems enable to improve performance and robustness of the wireless communication by taking advantage of the multipath phenomenon considered initially as a major drawback. Therefore they require a good port-to-port isolation between the feeds. This condition is particularly difficult to satisfy while the volume, dedicated to the antennas and wireless communication devices, is still decreasing which implies closer and closer radiating elements.

The multi-antenna system, Planar Inverted-F antenna (PIFA), has been widely used in wireless communications. It is desirable for many applications such as CDMA, GSM and Bluetooth due to its simple structure, wideband, good radiations patterns and diversity. Furthermore, planar inverted-F antennas are suitable for small-size mobile device due to its low profile, light weight and conformal structure [3]. As antennas should work when signals are obstructed, the diversity is convenient to deal with this situation.

[1] PhD student, Laboratory LEA, University of Batna, Algeria, hamdikenazih@yahoo.fr
[2] PhD student, IFSTTAR-LEOST, Villeneuve d'Ascq, France, e-mail: rafik.addaci@ifsttar.fr
[3] Prof., Laboratory LEA, University of Batna, Algeria, e-mail: t.fortaki@yahoo.fr
[4] Prof., Dept. of Applied Electronics and Information Technology, University POLITEHNICA of Bucharest, Romania, e-mail: strungar@elmed.pub.ro
[5] Prof., Dept. of Applied Electronics and Information Technology, University POLITEHNICA of Bucharest, Romania, e-mail: mickyungureanu@yahoo.de

The current paper proposes a model for analyzing multi-antenna systems based on two planar inverted-F antennas (PIFA). This model uses the neutralization line as a technique of isolation and artificial neural network (ANN) as modeling method. It allows us to obtain good performance in terms of resonant frequency, bandwidth and isolation level with an important time gain. Compared to other simulation software, this model gives also instantly and accurately results.

2. Neutralization line technique and limits

Among the several techniques developed to improve the isolation between the feeding ports of the multiple antennas placed very close one to the other, we can mention the neutralization line technique [4-6]. Within this solution, two Planar Inverted F Antennas (PIFAs) are connected by a thin metallic line positioned at the same level than the radiating plates of the PIFAs (Fig. 1). This thin and short line has naturally very high characteristic impedance and can be considered as an inductance. When this neutralization line is placed between the two PIFAs, a notch filter behavior is obtained for the |S21| parameter characterizing the coupling between the two inputs, with a tunable zero deep by changing the width and/or the length of this line. By optimizing these parameters, good results are then obtained with this technique in terms of isolation. However, if the length and/or the width of the PIFA, the distance between them or the relative position compared to the edge of the printed circuit board (PCB) have to be modified to answer to a new application, the performance especially in terms of isolation in the considered band are lost and all the parametric studies should be carried out again to optimize the new system, resulting in a significant time losses.

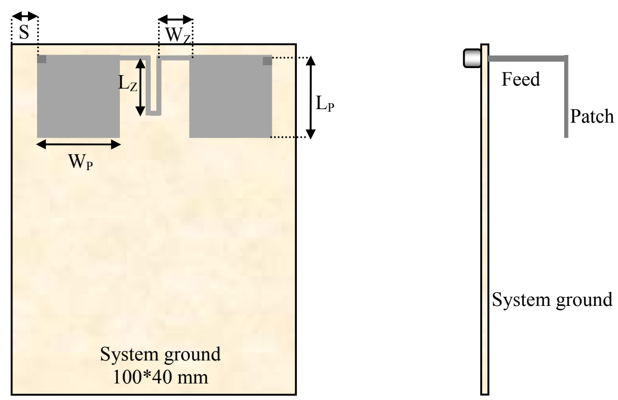

Fig. 1. Studied multi-antenna system

3. Artificial neural network (ANN)

Artificial neural networks (ANN) play an important role in optimization techniques. The Multilayer Perceptron (MLP) is the most artificial neural network used in electromagnetic structures [7-8]. It consists of multiple layers of nodes where each layer is fully connected to the next one. Each node, except the input, represents a processing element (neuron) with a nonlinear activation function. The MLP has been adapted for the calculation of the complex resonance frequency.

In this work, the standard algorithm backpropagation was used for MLP training (Fig. 2). This algorithm is based on the minimization of the quadratic error. Its name arises from the fact that the calculated output error is transmitted in opposite direction. It consists in:

Step1: Perform the forward propagation and calculate the error.

$$E_p = \frac{1}{2}\sum_{k=1}^{m}\delta_{p,k}^2 = \frac{1}{2}\sum_{k=1}^{m}(O_{p,k} - X_{p,l,k})^2 , \quad (1)$$

$$\delta_{p,k} = O_{p,k} - x_{p,l,k} , \quad (2)$$

where:

$O\,p = (O_{p,1}, O_{p,2}, \ldots\ldots, O_{p,m})$ is the desired vector.

Step2: Update the weights

Compute the gradient:

$$\nabla E_p = \delta_{p,k} x_{p,l,k}(1 - x_{p,l,k}) x_{p,l-1,j} , \quad (3)$$

2) Change the weights

For the output layer:

$$W_{l,k,j}(t+1) = W_{l,k,j}(t) + \Delta_p W_{l,k,j}(t) , \quad (4)$$

where:

$$\Delta_p W_{l,k,j}(t) = \mu(O_{p,k} - x_{p,l,k}) f'(y_{p,l,k}) x_{p,l-1,j} , \quad (5)$$

$$0<\mu<1 , \quad (6)$$

For the hidden layers:

$$W_{l-1,j,i}(t+1) = W_{l-1,j,i}(t) + \mu e_{p,l-1,j} x_{p,l-2,i} , \quad (7)$$

where:

$$\Delta_p W_{l,k,j} = \mu f'(y_{p,l-1,j}) X_{p,l-2,i} \sum_{k=1}^{m}(O_{p,k} - X_{p,l,k}) f'(y_{p,l,k}) W_{l,k,j} , \quad (8)$$

Step3: Go to step1 until the outputs match the desired vector.

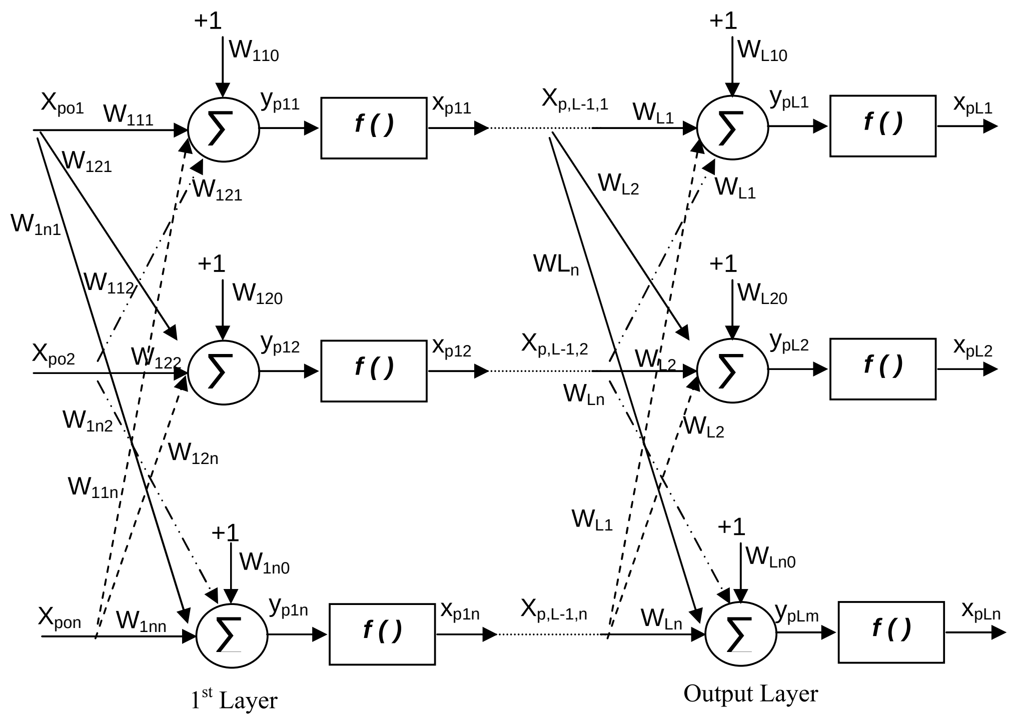

Fig. 2. Structure of a multilayer neural network

4. Antenna modeling

A database of 2200 input/output data was generated with the electro-magnetic simulation software HFSS in order to train and test the multi layer perceptron MLP. 2000 from the database were used in the training phase and 200 in the validation phase. The input data contains five parameters: LP/WP the length/width of the PIFAs, LZ/WZ the length/width of the neutralization line, and S the distance of the PIFA to the edge of the PCB (Fig. 1).

The output data contains the resonant frequency, the level of the adaptation parameter (|S11|) at this frequency, the -6dB bandwidth and the level of the isolation parameter (|S21|) at the resonant frequency and at the edge of the obtained bandwidth. The length/width of the PCB, the width of the feed, the width of the short circuit strips, and the height of the PIFAs are fixed to 100mm/40mm, 0.5mm, 0.5mm and 8mm respectively which is the common sizes of the small mobile devices. The input parameters were chosen between the [Min, Max] bands shown in (Table 1) in order to take into account the effect of the neutralization line and the variation of the resonant frequency between [1.75GHz, 3.65GHz].

Table 1

The input parameters for which the ANN model is valid

Parameters (mm)	L_P	W_P	L_Z	W_Z	S
Min	15	10	1	1	1
Max	30	15	26	7	6

Phase1:

The aim of this phase is to choose the best configuration of ANN to modulate the antenna. Only the resonance frequency was used as output in this step. Several architectures were designed by changing the number of the hidden layers and the number of neurons in each layer (Table 2). All architectures were trained using the back-propagation algorithm of Bayesian regularization. In the validation phase, the errors ERet (the error in the real part of the resonance frequency on the training set), ERiet (the error in the imaginary part of the resonance frequency on the training set), ERrvt (the error in the real part of the resonance frequency on the validation set) and ERivt (the error in the imaginary part of the resonance frequency on the validation set) were computed in order to determine the effective number of parameters. The architecture number twelve in the table was chosen as a model for antenna modeling due to its higher effective number of parameters. It consists in two hidden layers of 5 and 7 neurons.

Where:

$$ERret = \sum abs(f_r(ANN) - f_r(apprentissage)) \tag{9}$$

$$ERiet = \sum abs(f_i(ANN) - f_i(apprentissage)) \tag{10}$$

$$ERrvt = \sum abs(f_r(ANN) - f_r(apprentissage)) \tag{11}$$

$$ERivt = \sum abs(f_i(ANN) - f_i(apprentissage)) \tag{12}$$

Phase2:

In this phase, the two planar inverted F antenna (PIFA) was modeled by artificial neural network using the selected architecture in the phase1 (Fig. 3).

The results of this model (fr, |S11(fr)|, |S21(fr)|, |S21b|, |S21h|, bandwidth) were compared to those of HFSS for UMTS (1.92-2.17GHz) and LTE (2.5-2.7 GHz) (Fig. 4). For the UMTS/ LTE configuration the desired performance [|S11(fr)|, |S21(fr)|, |S21b|, |S21h|, BP] fixed in the program are [-15dB, -25dB, - 20dB, -20dB, ≥250MHz] / [-15dB, -15dB, -15dB, -15dB, ≥200MHz] respectively.

Table 2

Scenarios of architectures to achieve the ANN model required

Architectures		ERret (GHz)	ERiet (GHz)	ERrvt (GHz)	ERivt (GHz)	effective nbr of parameters %	$SSE<10^{-3}$ Learning
Nbr	Config						
1	3-3-2	50.954	1.5044	10.290	0.2157	87.50	Failed
2	3-4-2	25.645	0.8414	4.0286	0.1572	84.86	Failed
3	3-5-2	10.812	0.6636	2.7513	0.1687	89.54	Failed
4	3-6-2	6.0900	0.4959	1.3855	0.1440	92.04	Failed
5	4-4-2	7.7620	0.4670	1.5418	0.1116	89.34	Failed
6	4-5-2	4.6853	0.3584	1.0643	0.0731	93.22	Reached
7	4-6-2	5.6836	0.3165	1.5047	0.0814	92.30	Reached
8	4-7-2	5.0895	0.3453	1.2246	0.0693	94.62	Reached
9	5-2-2	14.456	0.6195	2.8748	0.1157	87.89	Failed
10	5-5-2	5.8080	0.3694	1.5051	0.0863	92.25	Reached
11	5-6-2	5.7226	0.3410	1.3910	0.0713	94.00	Reached
12	**5-7-2**	**4.4287**	**0.3845**	**1.0257**	**0.0696**	**96.66**	**Reached**
13	6-5-2	5.6089	0.3572	1.4117	0.0842	95.07	Reached
14	6-6-2	5.6043	0.3378	1.3670	0.0742	92.12	Reached
15	7-6-2	5.0278	0.3698	1.0805	0.0654	92.33	Reached

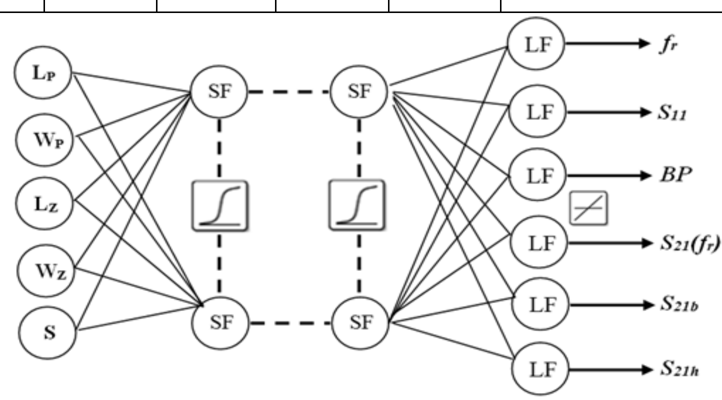

Fig. 3. Proposed ANN model: SF (sigmoid function), LF (linear function)

The optimized ANN model is able to estimate the outputs performance with a very good accuracy. The major advantage of the neural network model presented in this paper is the important time gain offered by this technique compared to other simulation tools like HFSS. Besides the time needed to create the database which is used for the training of the neural network and the time required to optimize the final model, the results are obtained very fast and quasi-instantaneous with the optimized ANN model. Knowing that HFSS takes 4 to 5 minutes for a single parametric study (one configuration), the difference between the time required using the ANN model is enormously important compared to the required HFSS time for the same number of studies.

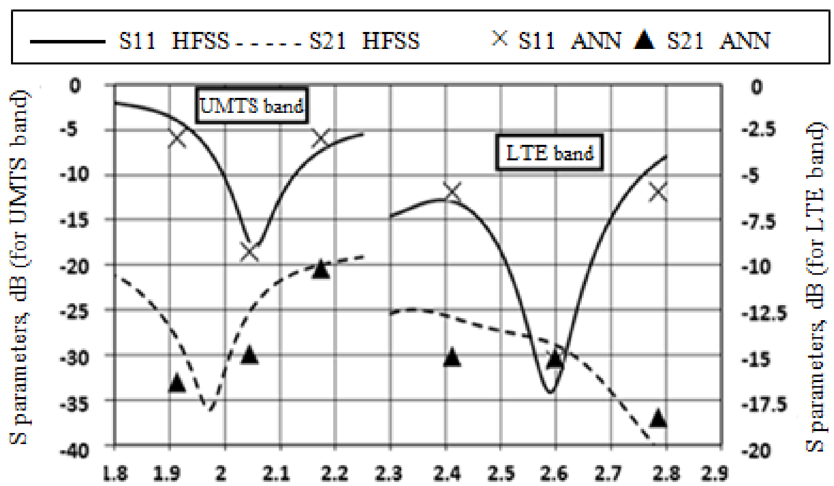

Fig. 4. Comparison of HFSS and ANN results

6. Conclusions

In this paper, a model dedicated to the analysis and modeling of multi-antenna systems based on two PIFA antennas connected by a neutralization line is presented. This model based on the artificial neural networks (ANN), offers a very significant time gain compared to other electromagnetic simulation software, with very accurate results compared with those obtained by these software. Conventional software are however always useful to generate the initial network training database.

REFERENCES

[1] *M.A. Jensen and J.W. Wallace*, A review of antennas and propagation for MIMO wireless communications, IEEE Ant. & Prop, **vol. 52**, no. 11, Nov. 2004, pp. 2810-2824.

[2] *C.C. Chiau, X. Chen and C.G. Parini*, A Compact Four-Element Diversity-Antenna Array for PDA Terminals in a MIMO System, Microwave and Optical Technology Letters, **vol. 44**, no. 5, 5th March 2005, pp. 408-412.

[3] *S.K. Oh, H.S. Yoon, and S.O. Park*, A PIFA-Type Varactor-Tunable Slim Antenna With a PIL Patch Feed for Multiband Applications, IEEE Antennas and Wireless Propagation Letters, **Vol.6**, 2007, pp. 103 - 105.

[4] *A. Diallo, C. Luxey, P. Le Thuc, R. Staraj and G. Kossiavas*, Study and Reduction of the Mutual Coupling Between Two Mobile Phone PIFAs Operating in the DCS1800 and UMTS Bands, IEEE Ant. & Prop, **vol. 54**, no. 11, Nov. 2006, pp. 3063-3074.

[5] *A. Diallo, C. Luxey, P. Le Thuc, R. Staraj and G. Kossiavas*, An efficient two-port antenna-system for GSM/DCS/UMTS multi-mode mobile phones, Elect. Lett., **vol. 43**, no. 7, 29th March 2007, pp. 369-370.

[6] *R. Addaci, A. Chebihi, A. Diallo, P. Le Thuc, C. Luxey and R. Staraj*, Multi-antenna systems for clamshell mobile phones, Proceedings of the Fourth European Conference on Antenna and Propagation (EuCAP), Barcelona, Spain, 12-16 April 2010, pp. 1-4.

[7] *R.E. Uhrig*, Introduction to artificial neural networks, Proceedings of the 21st international conference on industrial electronics, control, and instrumentation, **vol. 1**, 6-10 Nov 1995, pp. 33-37.

[8] *G. Antonini and A. Orlandi*, Gradient evaluation for neural-networks-based electromagnetic optimization procedures, IEEE Transactions on microwave theory and techniques, **vol. 48**, no. 5, May. 2000, pp. 874-876.