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NEUROCOMPUTATIONAL ANALYSIS OF COAXIAL FED STACKED PATCH ANTENNAS FOR SATELLITE AND WLAN APPLICATIONS

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Abstract—This paper presents a neural network based technique for the analysis of various stacked patch antennas, those can be applied for satellite and wireless local area network (WLAN) applications. In order to show the diversity of artificial neural network (ANN) modeling technique, two different trained neural networks were developed with different number of antenna geometrical parameters as inputs. These trained networks locate the operational resonance frequencies with their bands for stacked patch antennas (SPA) operating in the X-Ku (8 GHz–18 GHz) bands and WLAN bands (2 GHz–6 GHz). These frequency bands are useful for satellite communication and indoor wireless communication applications respectively. First ANN model takes design (geometrical) parameters of antenna like lower patch dimension, upper patch dimension, and height of air gap, as a input, whereas other NN model includes feed point location also as a input. The validity of the network is tested with the simulations results obtained from the full-wave Method of Moment (MoM) based IE3D and few experimental results obtained in the laboratory.

1. INTRODUCTION

In the current scenario of satellite and wireless communication, where number of users are increasing day by day, and demand of dual/multi broadband antenna is growing in leaps and bound. In this sense, analysis of dual resonance multilayer stacked patch antennas is going to be an inevitable component in the current trend of research, which led to new challenge in front of antenna designers. In high-performance spacecrafts, aircrafts, missile and satellite applications, where ease

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of installation, aerodynamics profile, size, weight and bandwidth are constraints, broadband microstrip antennas in X-Ku band are required, whereas wireless protocol such as Bluetooth, IEEE 802.11b, emphasizes the use of unlicensed frequency narrow bands for wireless local area network (WLAN) applications like mobile, laptop and hand held devices.

So tremendous effort has been made to analyze and enhance the overall performance of planar antennas. Multilayer and stacked forms of antennas are one type of that, which are capable to deliver the desired characteristics like broad bandwidth, dual- and multi-frequency behavior etc. [1–6]. Commercial and freeware computer aided design (CAD) models are available for the analysis of stacked patch antennas. These CAD models are based on the various analytical methods. Cavity model based models have been used for the analysis of patch antenna having electrically thin substrates. These models use closed-form formulas; hence they are simple but less accurate [7]. Available commercial softwares use numerical methods like FEM, full-wave MoM and FDTD. These methods are computer intensive and require high computational resources. With the increase in number of layers and radiating patches in the stacked patch antennas, the number of parameters also increases in calculating the resonant frequencies and/or bandwidth [8]. Because ANNs are capable of handling large number of inputs/outputs, they are suitable to form black-box model between them. A stacked patch antenna already has been analyzed with the help of ANN [8]. It was a tedious and time consuming task to develop ANN model of [8], because it involves large number of input geometrical parameters (L_1, L_2, h_1, h_2, ε_{r1} and ε_{r2}). It takes large number of epochs (2000) to be converged, while training. Also, a performance of this model is limited, as it delivers only two resonance frequencies for satellite band. Therefore, the present problem of analysis is a suitable candidate.

In the present work, two different models based on ANN techniques have been developed to analyze stacked patch antennas for two different applications. First ANN model has been used for the analysis of a dual resonant broadband stacked patch antenna, which can be applied for satellite communication applications (X-Ku band). The FCC (federal communications commission) has provided few license-free narrow bands, i.e., 2.4 GHz: 2403–2483 MHz, and 5 GHz: 5150–5250 MHz, for the WLAN community to utilize for indoor wireless communication applications. Second ANN model is useful for the analysis of a stacked patch antenna, which can covers these WLAN bands. In the proposed technique, the role of the ANN is to form a black-box model between the design dimensions of the antenna with its working frequencies and bandwidth.

An accurate and computationally fast analysis is an important building block for the design of stacked patch antennas. For that a stacked patch antenna geometry having a very few design (geometrical) parameters is the requirement. In order to fulfill that, in Section 2, a simplified antenna geometry will be proposed which involves a very few geometrical parameters. Implementation aspects of ANN will be covered thoroughly in Section 3. In Section 4, the final results obtained from the present approach are cross verified with IE3D computer simulation as well as experimental measurement work for dual resonance frequencies and bandwidth. A performance of ANN will include reflection coefficients ($|S_{11}|$ in dB) characteristics. Finally, Section 5 contains conclusions and future challenges in this area.

2. PROPOSED STACKED PATCH ANTENNA GEOMETRY

A multilayer stacked patch antenna can be fabricated on any suitable thin dielectric substrates by stacking patch radiators one above the other. The proposed structure is shown in Fig. 1.

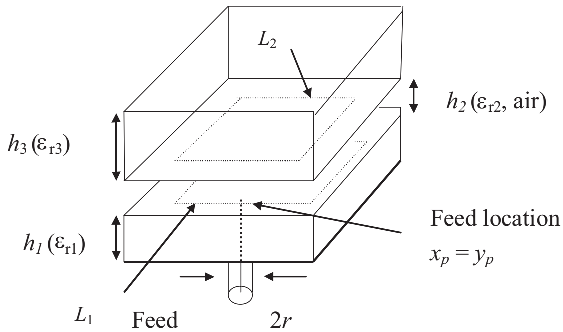

Figure 1. Coaxial fed dual patch SPA.

This structure consists of a lower activated patch and an upper patch, which is hanging from the superstrate. This upper patch superstrate is also helpful in protection of whole antenna. A lower and an upper patches have been chosen in square shape ($L_1 = W_1$ and $L_2 = W_2$), in order to simplify the analysis task. The upper patch is coupled parasitically with the lower patch. For satellite antenna analysis, the initial values were chosen as $L_1 = 8$ mm, $L_2 = 7$ mm, $\varepsilon_{r1} = 2.2$, $\varepsilon_{r2} = 1$, $\varepsilon_{r3} = 2.2$, $h_1 = 1.625$ mm, $h_2 = 5$ mm, $h_3 = 3.25$ mm, $x_p = y_p = 2.5$ mm. Similarly for WLAN antenna analysis, initial values were chosen as $L_1 = 25$ mm, $L_2 = 17$ mm, $\varepsilon_{r1} = 2.2$, $\varepsilon_{r2} = 1$, $\varepsilon_{r3} = 2.2$, $h_1 = 3.25$ mm, $h_2 = 3$ mm, $h_3 = 3.25$ mm. For WLAN antenna analysis, feed position was initialized at 6 mm as shown in Table 1. In order to reduce the surface wave, which usually exists in high value of dielectric substrates, the permittivity of the lower dielectric substrate and the upper dielectric superstrate were fixed at lower value of 2.2 in both types of antenna analysis and design. In all the cases, air gap is introduced between the two patches, which helps in controlling the frequency and bandwidth of SPA. For fabrication of the microstrip antenna in the laboratory, usually the dielectric is supplied with fixed value of thickness. Therefore, the thickness of layer, i.e., $h_1 = 1.625$ mm ($\varepsilon_{r1} = 2.2$) and $h_3 = 3.25$ mm ($\varepsilon_{r3} = 2.2$), is fixed for satellite antenna modeling. Similarly for modeling of WLAN antenna, thickness is fixed as $h_1 = 3.25$ mm ($\varepsilon_{r1} = 2.2$) and $h_3 = 3.25$ mm ($\varepsilon_{r3} = 2.2$).

Table 1. Antenna parameters.

Antenna Type	Parameters	L_1 (mm)	h_1 (mm)	ε_{r1}	L_2 (mm)	h_2 (mm)
Satellite Antenna	Initial	8	1.625	2.2	7	5
	Variation	6–11	fixed	fixed	4–10	0.3–10
WLAN Antenna	Initial	25	3.25	2.2	17	3
	Variation	20–40	fixed	fixed	10–20	0.3–5
Antenna Type	Parameters	ε_{r2}	h_3 (mm)	ε_{r3}	$x_p = y_p$ (mm)	
Satellite Antenna	Initial	1	3.25	2.2	2.5	
	Variation	fixed	fixed	fixed	fixed	
WLAN Antenna	Initial	1	3.25	2.2	6	
	Variation	fixed	fixed	fixed	3–8	

3. PROPOSED ANALYSIS METHODOLOGY

ANN already has been applied in the field of antenna analysis and design [8, 9]. Some of the published literature of using ANN in the field of antenna analysis and design reflects its usefulness and success [10–15]. Changes in the characteristics of electromagnetically coupled stacked patch antennas due to variations in the parameter are very complicated especially when closed-form formula do not exist. Some of the fixed variations in the parameters have been done to analyze these antennas, viz. to shift the resonant frequencies and bandwidth within band. An idea here is to develop a model using ANN. In most of the applications, the role of the network is to form a black-box mapping between a set of input geometrical parameters with their corresponding responses. Same characteristics of the ANN have been exploited here to achieve the operational resonance frequencies and bandwidth of the stacked patch antenna for specific design parameters. We now attempt to develop two different neural network models, to address the relationship between the resonant frequencies and associated bandwidth with the antenna design parameters. Initially these design variables of antenna were fixed in such a way so that the antenna can resonate in X-Ku band (within 8–18 GHz) and WLAN bands (within 2–6 GHz).

In the present work, both developed ANN models consist of two hidden layers and one output layer. It is a feed forward ANN, which utilizes error back propagation algorithm. Input vectors are presented to the first hidden layer and processed to output layer. Feed forward network finally yields the output vector. The entire procedure of ANN modeling was divided in three phases; (i) Data Generation. (ii) Development of the trained ANN model. (iii) ANN Testing. The user has to give the antenna design (geometrical) parameters as the inputs to the model and model outputs two frequencies with associated bandwidth. The three phases of the implementation are described as follows.

3.1. Data Generation

For satellite antenna modeling, three design variables, i.e., dimension of lower patch (L_1), dimension of upper patch (L_2), and height of the air gap (h_2), were chosen, whereas for WLAN antenna modeling, four design variables, i.e., dimension of lower patch, dimension of upper patch, height of the air gap and feed point location ($x_p = y_p$), were chosen. For generation of training data, these input parameter values were varied around the initial values. Initial parameters and all the range of the variation in the parameters of the SPA has been summarized in Table 1. It is observed from Table 1 that, it is enough to vary lower patch dimension as 6 to 11 mm, upper patch dimension as 4 to 10 mm and air gap as 0.3 to 10 mm to analyze the antenna within X-Ku band. Similarly for WLAN antenna analysis, range of the parameters were decided as lower patch dimension 20 to 40 mm, upper patch dimension 10 to 20 mm, and air gap height 0.3 mm to 5 mm. For this, feed point location was taken on the diagonal of the lower square patch and measured from the center. For WLAN antenna analysis, feed point location was varied from 3 to 8 mm. Simulations were performed for these values with the help of IE3D simulator software and the operating resonance frequencies along with their bandwidth were noted down from the responses. While data generation, it was kept in mind to take the dielectric constant of the lower laminate a higher value than that of the upper laminate and the relative dielectric constant of the upper laminate close to unity to give the best impedance bandwidth without compromising the antenna efficiency. During simulation, these input data about parametric values were discarded for which the operating frequencies fall beyond X-Ku and WLAN bands. Nearly 75% of generated data was used for training and rest of the data was used for testing.

3.2. ANN Training and Modeling

Training is done through the set of generated data. The training through the generalized back propagation rule involves application of input data set which includes input and associated output pairs. Input is propagated through the network and output values for each input is computed. This output is then compared with the desired value. In case of discrepancy, it may result some error signal. This error signal is then passed to each layer in the network in a backward manner. As per the error signal, weights are adjusted and calculated so that the final error is minimized. Developed ANN models are shown in Figs. 2(a) and 2(b).

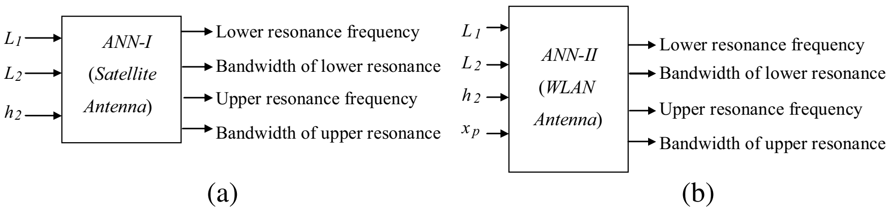

Figure 2. ANN models.

A multilayer perceptron trained in the backpropagation mode [16] was used, because these networks are more effective in solving function mapping problems.

3.3. ANN Testing

It is required to test the accuracy of trained neural networks to verify the model and done through the data set, which is also generated from the same simulator. A simultaneous training and testing methodology is employed. A one third of the data subset is used for simultaneous testing. There are generally four steps in the ANN modeling, i.e., assemble the training data, create the network object, train the network, and then simulate the network response to new inputs for testing. As the training progress, testing error is monitored. When testing error is minimized along with the training error after applying number of iterations and adjusting other training parameters, i.e., learning rate, performance ratio etc., then the model is considered to be generalized, viz. network is ready to respond accurately for new

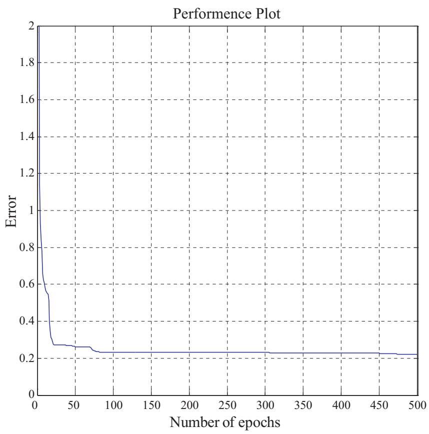

Figure 3. Performance plot of ANN.

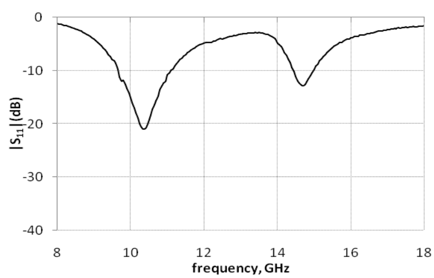

Figure 4. Simulated $|S_{11}|$ plot of satellite antenna.

Table 2. Neural network parameters.

S.N	Parameters	Values	
		ANN-1 (Satellite)	ANN-II (WLAN)
1	Network size	3×4×8×4	4×4×16×4
2	Number of neurons in first hidden layer	4	4
3	Number of neurons in second hidden layer	8	16
4	Number of neurons in output layer	4	4
5	Training algorithm	Backpropagation (LM)	Backpropagation (LM)
6	The number of epochs	500	500
7	Learning rate	0.72	0.72
8	Momentum coefficient	0.72	0.70

set of input data. Performance of the one of the model in terms of error with respect to number of epochs has been shown in Fig. 3. The parameters of the developed ANN models have been listed in Table 2.

4. RESULTS AND DISCUSSION

The validity of the trained neural network was tested with the test data set that was not used for training purpose. The neural network response was compared with the simulations and measured results. Simulated results were obtained from IE3D software and measured results were obtained experimentally from the fabricated

Table 3. ANN performance for satellite antenna.

A. N.	ANN-I Inputs (mm)			ANN-I Response (Resonance frequencies (GHz) and bandwidth)				IE3D (MoM) Response (Resonance frequencies (GHz) and bandwidth)				Experimental Response (Resonance frequencies (GHz) and bandwidth)			
	L_1	L_2	h_2	fr_1	BW_1 %	fr_2	BW_2 %	fr_1	BW_1 %	fr_2	BW_2 %	fr_1	BW_1 %	fr_2	BW_2 %
1	8.85	8.25	0.35	10.35	15.13	14.94	7.06	10.36	14.18	14.46	6.01	10.87	14.36	14.83	10.42

Table 4. ANN performance for WLAN antenna.

A. N.	ANN-II Inputs (mm)				ANN-II Response (Resonance frequencies (GHz) and bandwidth)				IE3D (MoM) Response (Resonance frequencies (GHz) and bandwidth)				Experimental Response (Resonance frequencies (GHz) and bandwidth)			
	L_1	L_2	h_2	x_p	fr_1	BW_1 %	fr_2	BW_2 %	fr_1	BW_1 %	fr_2	BW_2 %	fr_1	BW_1 %	fr_2	BW_2 %
1	38.12	13.52	1.75	4.98	2.45	3.69	5.13	6.22	2.447	3.67	5.12	6.27	2.483	3.53	5.21	4.76

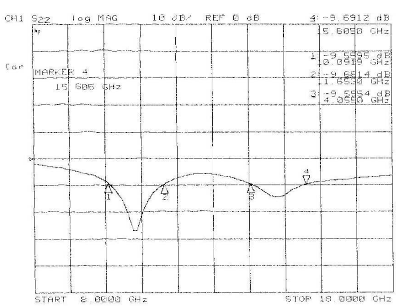

Figure 5. Measured $|S_{11}|$ plot of satellite antenna.

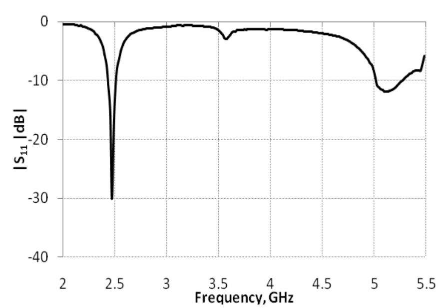

Figure 6. Simulated $|S_{11}|$ plot of WLAN dual-band antenna.

antennas. Fabricated antenna structures were measured for its resonant frequencies and bandwidth using HP8720B VNA in the laboratory. Reflection coefficients ($|S_{11}|$ in dB) for the simulated and experimentally measured antennas have been plotted in Fig. 4 to Fig. 7 for a broadband satellite antenna and a WLAN dual narrow band antenna respectively. One of the fabricated broadband satellite antennas is shown in Fig. 8. Numerical response from these plots has been mentioned in Tables 3 and 4, respectively. The accuracy of the network can be marked from these values.

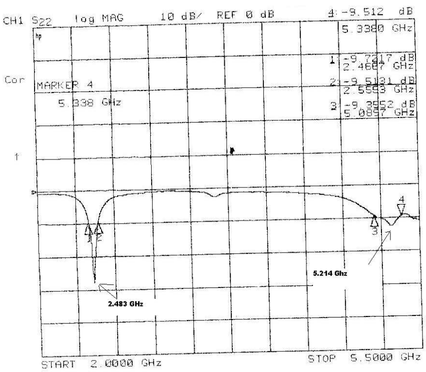

Figure 7. Measured $|S_{11}|$ plot of WLAN dual-band antenna.

Figure 8. Fabricated satellite antenna.

5. CONCLUSIONS

Two different trained neural network models were developed for the analysis of stacked patch antennas. These models are proved to be useful for locating the two resonance frequencies and bandwidth of stacked patch antennas. The main advantage of the neural network model is that it completely bypasses the repeated use of the simulators/codes in calculating the resonant frequencies and bandwidth, saving computation time and cost. In comparison with the previously developed ANN model, the proposed model is fast as it involves few input geometrical parameters only (L_1, L_2, and h_2). It takes only few numbers of epochs (500) to be converged while training. A performance wise also, proposed model seems to be better as it includes bandwidth also in the response. If some characteristics of the antenna i.e specific resonance frequency and associated bandwidth, has to be adjusted in real time application, then it is assumed that developed ANNs can come to the rescue. The difference in the f_{r1},

f_{r2}, BW_1 and BW_2 values in comparing with the experimental results is because of fabrication and experimental mechanical errors. Efforts are made to continually reduce these errors. It is expected that these antennas can be useful for satellite and WLAN applications. With the increasing interest in multiband/broadband patch antennas, it is also expected that the proposed analysis technique can be used effectively in locating the operating frequencies with associative bandwidth for other complicated structure of stacked patch antennas.

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