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Research Article

Levenberg-Marquardt and Conjugate Gradient Neuro-Modeling of Simulated Miniature Rectangular Microstrip Antenna

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ABSTRACT

Neural-network computational modules have recently gained recognition as an unconventional and useful tool for RF and microwave modeling and design. Neural networks can be trained to learn the behaviour of passive/active components/circuits. This work presents artificial neural network (ANN) for design of IE3D simulated miniature microstrip antenna. In the presented work, the artificial neural network is used for accurate determination of different parameters like resonant frequency, bandwidth, return loss, and voltage standing wave ratio (VSWR) of square and rectangular microstrip patch antenna. The developed neural network model which uses the data of simulated hundred antennas is based on Levenberg-Marquardt (LM) and conjugate gradient (CG) feed-back propagation. The developed ANN models for rectangular microstrip antennas (RMSAs) are in very good agreement with the experimental results available in the literature. The comparative analysis of developed models is presented which gives higher accuracy than that reported elsewhere.

Keywords: Artificial neural network; Rectangular microstrip antenna; Levenberg-Marquardt; Conjugate gradient.

1. Introduction

MICROSTRIP antenna (MSA) has wide range of applications from communication systems to biomedical systems. MSA consists of a metallic radiating patch on one side of thin dielectric substrate with the other side ground plane. The resonant frequency of MSA needs to be determined accurately as these MSAs have narrow bandwidth and can operate effectively in the vicinity of resonant frequency [1]. Various methods are available to calculate patch dimensions and resonant frequencies, bandwidth, return loss, VSWR, and etc. of different geometries of MSA. For execution of the present work, IE3D software has been used to design 100 RMSAs. The main parameters considered for the ANN modeling have been resonant frequency, bandwidth, return loss, and VSWR.

The coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas. As seen from Fig. 1, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation.

The simulation process used has been through IE3D electromagnetic software which is based on method of moments (MOM). For RMSA design, the dielectric used is FR4 with dielectric constant of 4.4. The effort has been made to design miniature antenna to reach ideal characteristics of antenna. The selection of length L, width W, and height h, for this purpose has been as follows:

Height h: 1 mm – 5.2 mm, step size 0.1,
Width W: 2 mm – 4.5 mm, step size 0.01,
Length L: 2 mm – 2.62 mm, step size 0.01.

The probe feed radius considered for the design is 0.25 mm.

The main objective of this paper is to demonstrate the efficacy of simple ANN model using FFBP & FF algorithm to calculate resonant frequency, bandwidth, return loss, and VSWR of

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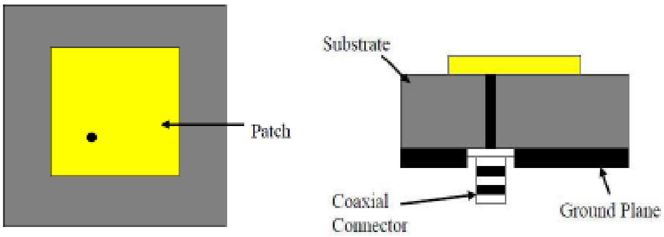

Figure 1: Coaxial-fed RMSA.

RMSA. Once the model is perfected, it can be an effective substitute to computationally intensive physics or EM models [2].

2. Neural network development

Neural network (NN) technology is an emerging technology in the microwave area for microwave modeling, simulation, optimization, and design [3]. NNs, also called artificial neural networks (ANNs), are information processing systems with their design inspired by the studies of the ability of the human brain to learn from observations and to generalize by abstraction [4].

NN techniques are in use for a wide variety of microwave applications such as embedded passives [5], transmission line components [6–8], vias [9], bends [10], coplanar waveguide (CPW) components [11], spiral inductors [12], FETs [13], amplifiers [14, 15], etc. NNs are used in impedance matching [16, 17], inverse modeling [18], measurements [19], and synthesis [20]. Multilayer perceptron (MLP), radial basis function (RBF), knowledge based neural network (KBNN), wavelet network, and recurrent neural network (RNN) are commonly used as ANN structures.

Selection of structure and training algorithm are two major issues in developing the ANN model. The most important and time consuming step in model development is training. The microwave behaviour is learned through this process. The ANN model uses the measured or simulated data for training. Training is an optimization process in the weight space and is often done using optimization-based training algorithm such as backpropogation (BP) and feed-forward. Trained NN models can be used in high level simulation and design, providing fast answers to the task they have learned [2, 21].

Training algorithms are quintessential to NN model development. Any alternative structure may still fail to give a better model, unless trained by a suitable training algorithm [3]. The proper training algorithm manages to reduce the training time by achieving better accuracy.

A distinct advantage of neural computation is that, after proper training, it completely bypasses the repeated use of complex iterative processes for any new design presented to it.

In the model under reference, feed-back propagation by using LM and CG methods have been used for the modeling of MSA.

3. Data generation

The first step in neural model development is the generation and collection of data for training and testing the neural models. Data generation generally involves use of a data generator to obtain the output values for each input design. The total number of samples, to be generated, is chosen so that the developed neural model best represents the original problem. There are two types of data generators for microwave applications, namely measurement and simulation. The choice of data generator depends on both the application and the availability of the data generator [4].

Data generation by simulation also has a number of advantages. Any input parameter can be changed easily, because it is only a numerical change and does not involve any physical/manual change. Any response can be computed as long as its evaluation is supported by the simulator. Errors creeping into simulation data due to floating point truncation/round-off operations are found to be much smaller compared to the errors that can be present in measurement data due to equipment tolerances.

In the present model, the data has been generated by using IE3D software. A total of one hundred rectangular microstrip antennas were developed of which 70 antennas have been used for training of the ANN. The remaining 30 have been used for testing of the developed ANN model.

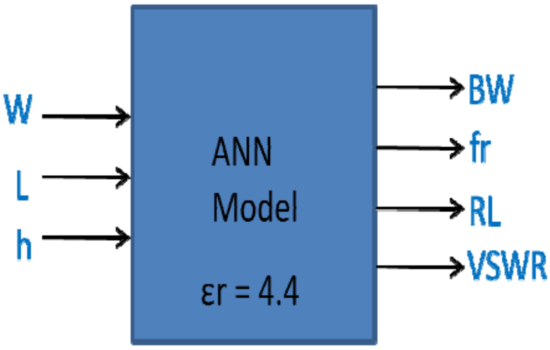

Figure 2: Analysis model of ANN for prediction of four parameters.

4. ANN model

The developed analysis model is used for the prediction of four different parameters like resonant frequency, bandwidth, return loss, and VSWR. The developed model has 3 inputs and 4 outputs as shown in Fig. 2. The ANN modeling is performed by using feed-forward BP.

In feed-forward BP ANN modelling two different algorithms viz. CG and LM algorithms are used.

4.1. CG algorithm

The one hidden layer structure is used for the design with 3 neurons in the input layer, 12 in the hidden, and 4 in the output layer. Initially, 200 epochs were considered but it did not yield a satisfactory result. The error was high. This error was minimized by increasing the epochs from 200 to 800. The developed model gives average error of 2.76 with the use of sigmoid function. The epochs given for training the model were 800 from which it took only 500 epochs for the training. The

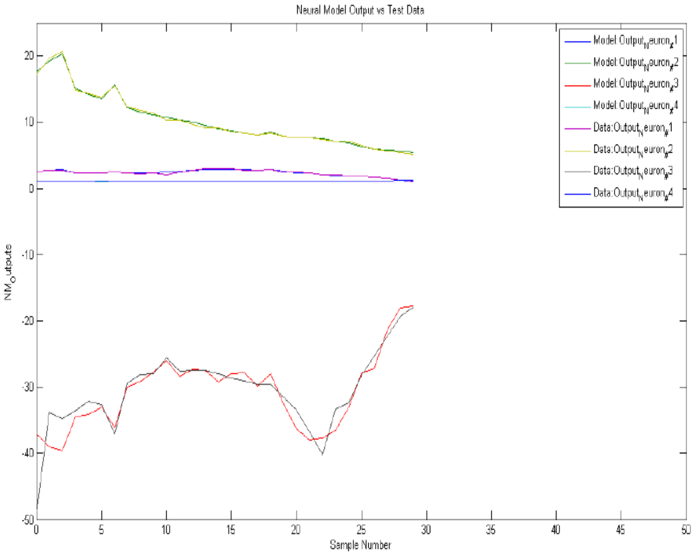

Figure 3: Graphical representation of testing of ANN model using CG.

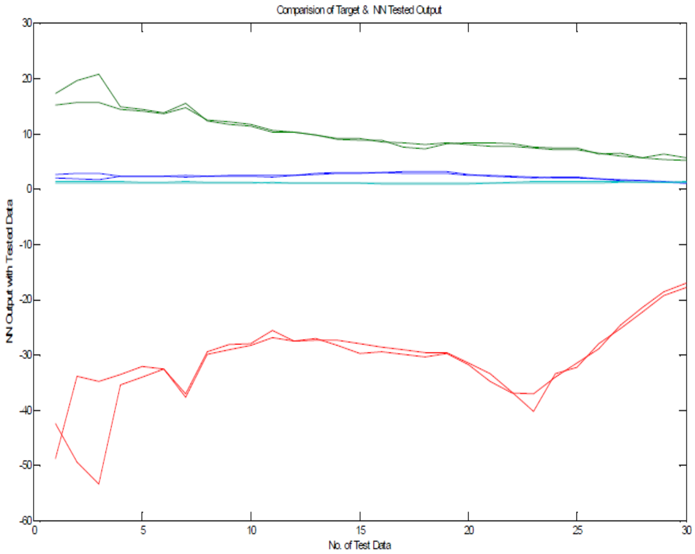

Figure 4: Graphical representation of testing of ANN model using LM.

Table 1: Testing results of ANN model based on CG.

Sr. No	BW Target	ANN BW	error	fr Target	ANN fr	error	RL Target	ANN RL	error	VSWR Target	ANN VSWR	error
1	2.56	2.571159	-0.01116	17.22	17.56128	-0.34128	-48.76	-37.028	-11.732	1.006	1.0321916	-0.02619
2	2.74	2.712189	0.027811	19.55	19.27175	0.278247	-33.81	-39.0674	5.257413	1.042	1.0209175	0.021083
3	2.76	2.798601	-0.0386	20.71	20.30619	0.40381	-34.79	-39.627	4.837033	1.037	1.0172361	0.019764
4	2.35	2.393413	-0.04341	14.89	15.06801	-0.17801	-33.57	-34.4777	0.907722	1.043	1.0465676	-0.00357
5	2.36	2.331762	0.028238	14.32	14.12279	0.197207	-32.12	-34.1723	2.052348	1.053	1.0488895	0.00411
6	2.32	2.293456	0.026544	13.75	13.46605	0.283953	-32.67	-33.0779	0.407873	1.106	1.0546283	0.051372
7	2.49	2.430052	0.059948	15.5	15.61506	-0.11506	-37.1	-36.1158	-0.98419	1.028	1.0383598	-0.01036
8	2.32	2.316057	0.003943	12.3	12.18286	0.117145	-29.41	-29.9204	0.510439	1.073	1.0715874	0.001413
9	2.25	2.282934	-0.03293	11.73	11.52431	0.205693	-28.17	-29.2079	1.037895	1.083	1.0753679	0.007632
10	2.29	2.274334	0.015666	11.427	11.14714	0.279863	-27.99	-27.7247	-0.26529	1.083	1.0824738	0.000526
11	2.08	2.485117	-0.40512	10.28	10.65874	-0.37874	-25.58	-26.0007	0.420715	1.115	1.0921004	0.0229
12	2.49	2.621746	-0.13175	10.28	10.25149	0.028506	-27.53	-28.3722	0.842164	1.087	1.0823733	0.004627
13	2.79	2.760011	0.02999	9.707	9.980168	-0.27317	-27.44	-27.2872	-0.15275	1.094	1.0869629	0.007037
14	3	2.868258	0.131742	9.134	9.461723	-0.32772	-27.42	-27.5074	0.087421	1.088	1.0849339	0.003066
15	3	2.89947	0.10053	9.101	8.960087	0.140913	-28.01	-29.1339	1.123879	1.082	1.0769402	0.00506
16	2.96	2.919853	0.040147	8.561	8.701639	-0.14064	-28.617	-27.9545	-0.6625	1.077	1.079873	-0.00287
17	2.76	2.862314	-0.10231	8.258	8.295455	-0.03746	-29.109	-27.9046	-1.20441	1.072	1.0757442	-0.00374
18	2.73	2.780302	-0.0503	7.988	8.001825	-0.01382	-29.575	-29.823	0.247977	1.068	1.0656767	0.002323
19	2.83	2.893095	-0.0631	8.258	8.390596	-0.1326	-29.587	-27.986	-1.60103	1.068	1.0769476	-0.00895
20	2.49	2.554174	-0.06417	7.955	7.956798	-0.0018	-31.5	-32.3499	0.849922	1.054	1.0512718	0.002728
21	2.41	2.390081	0.019919	7.673	7.68388	-0.01088	-33.48	-36.2679	2.7879	1.0436	1.0334146	0.010185
22	2.36	2.275159	0.084841	7.685	7.611692	0.073308	-36.7	-38.0271	1.327122	1.0301	1.0253421	0.004758
23	2.12	2.043275	0.076725	7.382	7.521435	-0.13944	-40.264	-37.7154	-2.54864	1.019	1.0269306	-0.00793
24	2.05	1.962188	0.087812	7.11	7.096778	0.013222	-33.37	-36.4706	3.100585	1.042	1.0328215	0.009178
25	1.98	1.943277	0.036723	7.07	6.887163	0.182837	-32.32	-33.0647	0.744682	1.048	1.0482061	-0.00021
26	1.78	1.81637	-0.03637	6.505	6.327625	0.177375	-28.06	-27.8834	-0.17655	1.082	1.0866659	-0.00467
27	1.685	1.685566	-0.00057	5.93	5.903431	0.026569	-25.315	-27.1393	1.824265	1.115	1.1145492	0.000451
28	1.51	1.571564	-0.06156	5.66	5.826746	-0.16675	-22.285	-21.3743	-0.9107	1.165	1.1742202	-0.00922
29	1.24	1.296298	-0.0563	5.35	5.674027	-0.32403	-19.345	-18.0306	-1.31438	1.2425	1.2505097	-0.00801
30	1.11	0.99604	0.11396	5.089	5.430126	-0.34113	-17.92	-17.7547	-0.16531	1.29	1.3081248	-0.01812

Table 2: Testing results of ANN model based on LM.

Sr. No.	BW Target	ANN BW	error	fr Target	ANN fr	error	RL Target	ANN RL	error	VSWR Target	ANN VSWR	error
1	2.56	2.008	0.552	17.22	15.235	1.985	-48.76	-42.452	-6.308	1.006	1.298	-0.292
2	2.74	1.790	0.950	19.55	15.618	3.932	-33.81	-49.505	15.695	1.042	1.296	-0.254
3	2.76	1.691	1.069	20.71	15.634	5.076	-34.79	-53.403	18.613	1.037	1.288	-0.251
4	2.35	2.228	0.122	14.89	14.300	0.590	-33.57	-35.455	1.885	1.043	1.277	-0.234
5	2.36	2.273	0.087	14.32	13.990	0.330	-32.12	-34.050	1.930	1.053	1.265	-0.212
6	2.32	2.313	0.007	13.75	13.621	0.129	-32.67	-32.626	-0.044	1.106	1.249	-0.143
7	2.49	2.155	0.335	15.5	14.693	0.807	-37.1	-37.740	0.640	1.028	1.288	-0.260
8	2.32	2.370	-0.050	12.3	12.499	-0.199	-29.41	-29.979	0.569	1.073	1.185	-0.112
9	2.25	2.395	-0.145	11.73	12.107	-0.377	-28.17	-29.180	1.010	1.083	1.158	-0.075
10	2.29	2.404	-0.114	11.427	11.652	-0.225	-27.99	-28.260	0.270	1.083	1.128	-0.045
11	2.08	2.438	-0.358	10.28	10.481	-0.201	-25.58	-26.880	1.300	1.115	1.048	0.067
12	2.49	2.491	-0.001	10.28	10.316	-0.036	-27.53	-27.496	-0.034	1.087	1.040	0.047
13	2.79	2.649	0.141	9.707	9.725	-0.018	-27.44	-27.113	-0.327	1.094	0.995	0.099
14	3	2.776	0.224	9.134	8.979	0.155	-27.42	-28.314	0.894	1.088	0.970	0.118
15	3	2.799	0.201	9.101	8.785	0.316	-28.01	-29.702	1.692	1.082	0.984	0.098
16	2.96	2.904	0.056	8.561	8.810	-0.249	-28.617	-29.390	0.773	1.077	0.943	0.134
17	2.76	3.148	-0.388	8.258	7.539	0.719	-29.109	-29.863	0.754	1.072	0.874	0.198
18	2.73	3.128	-0.398	7.988	7.215	0.773	-29.575	-30.423	0.848	1.068	0.886	0.182
19	2.83	3.059	-0.229	8.258	8.096	0.162	-29.587	-29.697	0.110	1.068	0.896	0.172
20	2.49	2.671	-0.181	7.955	8.280	-0.325	-31.5	-31.784	0.284	1.054	0.946	0.108
21	2.41	2.334	0.076	7.673	8.323	-0.650	-33.48	-34.838	1.358	1.0436	1.047	-0.004
22	2.36	2.151	0.209	7.685	8.107	-0.422	-36.7	-36.875	0.175	1.0301	1.117	-0.087
23	2.12	2.043	0.077	7.382	7.480	-0.098	-40.264	-37.030	-3.234	1.019	1.273	-0.254
24	2.05	2.075	-0.025	7.11	7.440	-0.330	-33.37	-34.016	0.646	1.042	1.369	-0.327
25	1.98	2.078	-0.098	7.07	7.337	-0.267	-32.32	-31.538	-0.782	1.048	1.427	-0.379
26	1.78	1.773	0.007	6.505	6.211	0.294	-28.06	-29.022	0.962	1.082	1.390	-0.308
27	1.685	1.499	0.186	5.93	6.441	-0.511	-25.315	-24.700	-0.615	1.115	1.292	-0.177
28	1.51	1.536	-0.026	5.66	5.657	0.003	-22.285	-21.469	-0.816	1.165	1.186	-0.021
29	1.24	1.348	-0.108	5.35	6.211	-0.861	-19.345	-18.727	-0.618	1.2425	1.182	0.060
30	1.11	1.050	0.060	5.089	5.574	-0.485	-17.92	-17.114	-0.806	1.29	1.256	0.034

training error achieved is 0.0193 with worst case error of 34.51 with a coefficient of correlation at 0.996. The testing result is displayed as a graph in Fig. 3 and numerical presentation is set out in Table 1.

4.2. LM algorithm

The developed model consists of three layers, i.e. input layer, hidden layer, and output layer. The initial consideration for ANN modeling had 3 neurons in input layer, 15 in the hidden layer, and 4 neurons at output layer with 30 epochs. So, as to derive good result from the developed model, the number of epochs had to be improved from 30 to 150. The testing result is displayed as a graph in Fig. 4 and numerical details are presented in Table 2. The output of ANN model is compared with the target data where LM-ANN model shows error as 0.0237, average error of 0.426618 with worst case error of 18.613 and the coefficient of correlation of 0.992.

5. Conclusion

The comparison of developed models for prediction of different parameters of microstrip antenna is given in Table 3. The accuracy for ANN model with CG is 99.64%, for ANN model with LM is 95.73%. The accuracy of the CG-ANN model is high amongst the developed ANN models. Therefore, it can be concluded that ANN is one of the best alternative for the detailed EM simulation software as it gives accurate result within shortest time, whereas it requires much more time to design MSA by using IE3D software. So, it proves a time economiser device/technique.

Table 3: Comparison of accuracy of the developed ANN models.

Sr. No.	ANN Model	Parameter	Average Deviation	Error (%)	Accuracy (%)	Accuracy of ANN Model
1	CG	fr	-0.01713	-0.16772	99.83	**99.64**
		BW	-0.0071	-0.3052	99.69	
		RL	0.22165	-0.729	99.27	
		VSWR	0.00247	0.2292	99.77	
2	LM	fr	0.3338	3.269	96.73	95.73
		BW	0.074598	3.205	96.79	
		RL	1.2273	4.0382	95.96	
		VSWR	-0.0706	6.5309	93.46	

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