Artificial Neural Network Model for Suspended Shorted Rectangular Microstrip Antennas

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ABSTRACT
The bandwidth in half wave or quarter wave length microstrip antennas is increased by using suspended configuration in which the radiating patch is suspended above the ground plane of finite air gap. While using thicker substrate, a closed form expressions for calculating edge extension length due to the fringing fields in shorted patch, is not available. In this paper, an artificial neural network model to calculate the shorted patch length and edge extension length for air suspended shorted rectangular microstrip antenna over wide frequency range (500 to 6000 MHz) and on thicker air substrate ($0.04\lambda_0$ to $0.1\lambda_0$) is proposed. The resonance frequency calculated by using proposed neural network model closely agrees with the simulated and measured results. Thus, proposed model can be used to accurately calculate shorted patch length for shorted rectangular microstrip antenna.

Keywords
Compact microstrip antenna, Shorted Rectangular Microstrip antenna, Artificial Neural Network model, Supervised Network, Back Propagation Algorithm.

1. INTRODUCTION
The broadband microstrip antenna (MSA) is realized by fabricating the patch on lower dielectric constant thicker substrate [1 – 3]. In most of the reported literature, patch is suspended in air thereby realizing dielectric constant of unity. In MSAs, regular shapes for radiating patch like, rectangular, circular, equilateral triangular, isosceles, elliptical, etc are used. On thinner substrates ($h \leq 0.03\lambda_0$), resonance frequency formulation for these regular shapes is available [1 – 3]. While calculating the resonance frequency, effective patch dimensions are needed to be calculated, which accounts for extension in length due to fringing fields present across the patch periphery. The equations for the same are available on thinner substrate. The compact shorted rectangular MSA (RMSA) is realized by placing the shorting post/plate along the zero field line at its fundamental TM_{10}/TM_{01} mode and by using half of the shorted patch. While calculating the resonance frequency of shorted RMSA, an edge extension length is added to patch length or width. The expression for the same is available for thinner substrates. However, they are not reported for thicker substrates over wide range of resonance frequencies. Therefore dimensions of shorted RMSA cannot be accurately calculated at the desired resonance frequency while optimizing them on thicker air substrate ($h > 0.05\lambda_0$). The artificial neural network (ANN) model has been widely used to analyze MSAs [4 – 8]. However in the reported literature, ANN model for MSA over wide range of frequencies and substrate thickness is not reported [4 – 7]. In this paper, an ANN model for predicting the length of shorted RMSA and its edge extension length, over 500 to 6000 MHz frequency range and for air substrate having thickness in the range of $0.04\lambda_0$ to $0.1\lambda_0$ is proposed. The resonance frequency in shorted RMSA calculated using ANN model shows closer agreement with simulated and measured results. Thus the proposed model will be helpful to design shorted RMSAs at any frequency. In the proposed work, first the training data set is generated using IE3D software using finite ground plane [9]. This was further used to develop ANN model. To generate the measured data, shorted RMSA were fabricated using copper plate of finite thickness and was coaxially fed using N-type connector of 0.32 cm inner wire diameter. The measurement was carried out on finite square ground plane of side length 30 cm using ZVH-8 vector network analyzer.

2. SHORTED RMSA
The coaxially fed RMSA is shown in Fig. 1(a, b). The RMSA is suspended above the ground plane with an air gap of 'h'. The resonance frequency of RMSA for the given patch dimension is calculated by using equation (1) [3].

$$f_r = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{W_e}\right)^2} \qquad (1)$$

The 'L_e' and 'W_e' are the effective patch dimensions that accounts for the extension in length due to fringing fields. The 'm' and 'n' are the mode indices. The equations for extension length due to fringing fields in suspended RMSA for thicker substrates are not available. Recently ANN model to calculate the patch length and edge extension length on thicker air substrate has been reported [10]. It gives resonant length that gives frequency of within 5% with respect to simulated and measured values [10]. The compact shorted RMSA is realized by placing shorting post/plate along the zero field line at fundamental TM_{10} mode in RMSA and using only half of the shorted patch, as shown in Fig. 1(c, d). By suitably modifying the resonance frequency equation of RMSA, an equation for shorted RMSA is developed [11] as given in equation (2). Here 'L_e' and 'W_e' are the effective patch dimensions which accounts for fringing field extension length. The closed form equations to calculate the fringing field length on thicker substrates over wide frequency range is not available. Due to which the patch dimensions cannot be accurately calculated. To calculate the shorted patch length and an extension length due to fringing fields, an ANN model for shorted patch is developed.

$$f_r = \frac{c}{\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{2W_e}\right)^2} \qquad (2)$$

m = 1/4, 3/4, 5/4, … and n = 0, 1, 2,…

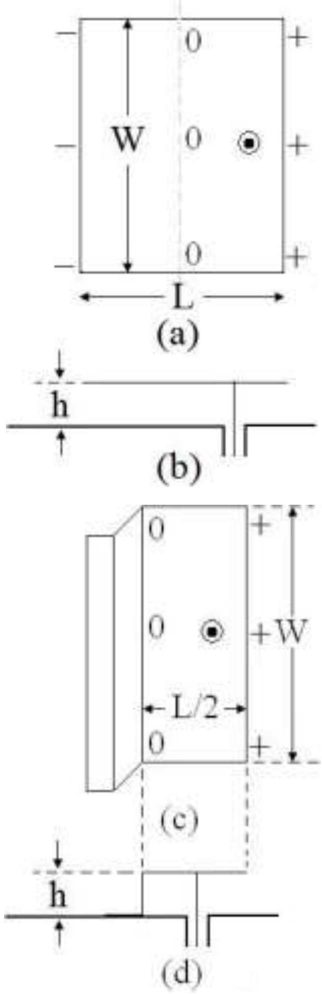

Fig 1: (a) Top and (b) views of RMSA and (c) top and (d) side views of shorted RMSA

3. ANN MODEL FOR SHORTED RMSA

The ANN model is developed for substrate thickness varying from 0.02 to 0.1λ_0 and over frequency range of 500 to 6000 MHz. Since in most of the reported broadband RMSA configurations, an air substrate is used (as it helps in realizing maximum radiating efficiency), the same is used while developing ANN model. While developing an ANN model, training data sets is generated using IE3D software at given frequency and for increasing substrate thickness. At given frequency, for substrate thickness ‘h’, the shorted RMSA length is taken equal to quarter wave in length. For optimum gain, patch width is selected to be 1.2 times the patch length [3]. Further shorted RMSA is simulated using IE3D software and peak in the resonance curve is noted. If the peak does not coincide with the desired patch resonance frequency, shorted patch length is further adjusted and the patch is simulated again. This procedure is repeated un-till peak in the resonance curve coincides with the desired frequency. For this frequency matching, simulated patch length (L) is noted and fringing field extension length is calculated by using the following equation.

$$\Delta l = \lambda/4 - L \qquad (3)$$

At a given frequency for six to eight substrate thickness values, data set of shorted patch length and fringing field extension length is calculated. This procedure is repeated over wide frequency range and at different substrate thickness. The above procedure for generation of training data sets is shown in Fig. 2. The data sets were generated at every 100 MHz frequency intervals over 500 to 6000 MHz frequency band. At each frequency parameters like, edge extension length in terms of substrate thickness, shorted patch length, frequency and dielectric constant of substrate (air in this case) are used to develop an ANN model as discussed below.

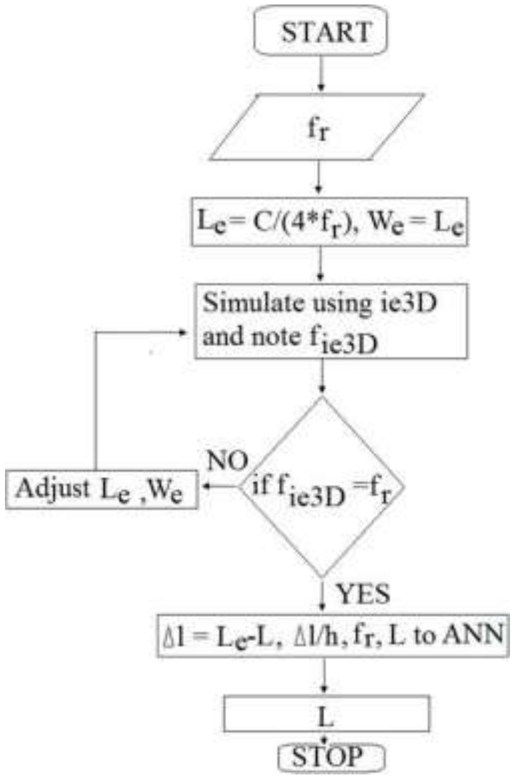

Fig 2 Flowchart for calculating shorted RMSA length

The feed-forward standard back-propagation algorithm is used as a neural network model for shorted RMSA. This is a supervised neural network model. The neural network model for shorted RMSA is shown in Fig. 3(a, b).

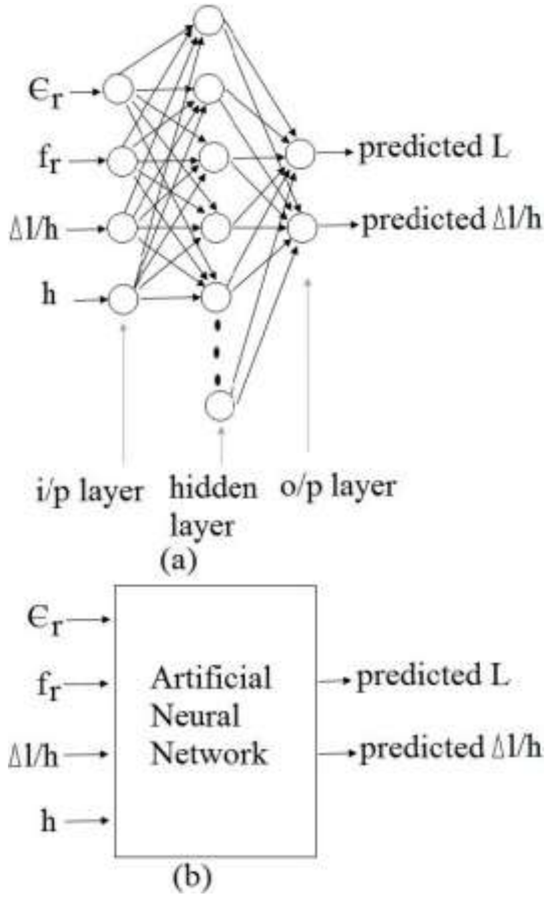

Fig 3 (a, b) ANN model for shorted RMSA

The supervised network is trained using input data and target data. The neural network learns from the input data and transforms input data into a desired response with the help of target data. They can approximate virtually any input-output map. They have been shown to approximate the performance of optimal statistical classifiers in difficult problems. The basic MLP (multi-level perceptron) building unit is a simple model of artificial neurons. This unit computes the weighted sum of the inputs plus the threshold weight and passes this sum through the activation function. In a multi-layer perceptron, the outputs of the units in one layer forms the inputs to the next layer. The weights of the network are usually computed by training the network using the back propagation algorithm. The supervised network, which has a configuration of 4 input neurons, 10 hidden neurons in a hidden layer and 2 output neurons which is trained for 50 epochs. The ANN model is trained with 6 samples and tested with the samples which fall under $0.1\lambda_0$ samples determined according to the definition of the problem. The parameters fed to the input of ANN are substrate thickness, fringing field extension length, dielectric constant at different resonant frequencies. The patch side length at different resonant frequencies and for different substrate thickness is predicted at the output of a trained neural network. For the predicted value, RMSA is simulated using IE3D software and the resonance frequency in its resonance curve is noted. The % error between the simulated and actual desired value (as given by ANN model) is calculated. The results obtained using ANN model for different frequencies and substrate thickness are tabulated in Table 1 to 15. They show close matching with simulated frequencies. The measurements were carried out at each frequency points as given in respective tables. In measurements the patch is fabricated using copper plate and it was suspended in air using foam spacer support placed towards the antenna corners. The foam spacer has dielectric constant close to unity, hence it does not affect the overall dielectric constant of the antenna. The measurement was carried out using R & S VNA (ZVH 8). The measured values are also in close agreement with predicted and simulated results.

Table 1 - Comparison between simulated, predicted and measured results around 500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	0.0083	499	500	486	0.2
1.0	0.0167	490.6	500	491	1.88
1.5	0.025	505	500	499	1
2	0.033	501	500	490	0.2
2.5	0.042	517.6	500	502	3.52
3	0.05	492.4	500	489	1.52

Table 2 - Comparison between simulated, predicted and measured results around 900 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	0.015	906	900	889	0.667
1	0.03	908	900	896	0.88
1.5	0.045	878	900	906	2.44
2	0.06	898	900	885	0.22
2.5	0.075	896	900	910	0.44
3	0.09	908	900	889	0.88

Table 3 - Comparison between simulated, predicted and measured results around 1000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	.0167	1016	1000	998	1.6
1	0.033	1016	1000	1020	1.6
1.5	0.05	968	1000	995	3.2
2	0.067	1004	1000	1011	0.4
2.5	0.083	1016	1000	982	1.6
2.8	0.093	1003	1000	1010	0.3

Table 4 - Comparison between simulated, predicted and measured results at around 1100 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	0.018	1106	1100	1080	0.54
1	0.037	1112	1100	1092	1.09
1.5	0.055	1126	1100	1113	2.36
2	0.073	1096	1100	1108	0.36
2.5	0.092	1070	1100	1066	2.72
2.8	0.103	1078	1100	1075	2

Table 5 - Comparison between simulated, predicted and measured results at around 1200 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	0.02	1208	1200	1196	0.67
1	0.04	1196	1200	1220	0.33
1.5	0.06	1218	1200	1192	1.5
2	0.08	1210	1200	1205	0.833

Table 6 - Comparison between simulated, predicted and measured results at around 1500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.5	0.025	1500	1500	1496	0
1	0.05	1500	1500	1488	0
1.5	0.075	1510	1500	1502	0.67
2	0.1	1442	1500	1460	0.53

Table 7- Comparison between simulated, predicted and measured results at around 2000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.3	0.02	2006	2000	2001	0.3
0.6	0.04	2042	2000	2036	2.1
0.9	0.06	2032	2000	2012	1.6
1.2	0.08	2028	2000	2004	1.4

Table 8- Comparison between simulated, predicted and measured results at around 2500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.2	0.0167	2468	2500	2514	1.28
0.4	0.033	2488	2500	2495	0.48
0.6	0.05	2514	2500	2519	0.56
1	0.0833	2527	2500	2465	1.08
1.2	0.1	2422	2500	2516	3.12

Table 9 - Comparison between simulated, predicted and measured results at around 3000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.2	0.02	2956	3000	2948	1.466
0.4	0.04	2953	3000	3002	1.566
0.6	0.06	2928	3000	2912	2.4
0.8	0.08	2888	3000	3052	3.733

Table 10 - Comparison between simulated, predicted and measured results at around 3500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.0117	3456	3500	3516	1.26
0.2	0.023	3488	3500	3496	0.34
0.4	0.047	3536	3500	3542	1.03
0.6	0.07	3616	3500	3465	3.31
0.8	0.09	3632	3500	3612	3.77

Table 11 - Comparison between simulated, predicted and measured results at around 4000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.0133	4003	4000	3989	0.075
0.2	0.0267	4066	4000	4012	1.65
0.3	0.04	3910	4000	4028	2.25
0.4	0.053	4100	4000	3966	2.5
0.7	0.093	3960	4000	4102	1

Table 12 - Comparison between simulated, predicted and measured results at around 4500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.015	4480	4500	4498	0.44
0.2	0.0299	4550	4500	4510	1.11
0.3	0.0449	4570	4500	4482	5
0.4	0.0599	4680	4500	4592	4

Table 13 - Comparison between simulated, predicted and measured results at around 5000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.0167	5002	5000	4998	0.04
0.2	0.033	5044	5000	4898	0.88
0.3	0.05	5093	5000	5012	1.86
0.4	0.066	5184	5000	5101	3.68

Table 14 - Comparison between simulated, predicted and measured results at around 5500 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.018	5352	5500	5496	2.69
0.2	0.037	5296	5500	5501	3.71
0.4	0.0733	5296	5500	5520	3.71

Table 15 - Comparison between simulated, predicted and measured results at around 6000 MHz

h (cm)	h/λ_o	f_{ie3d} (MHz)	f_{ANN} (MHz)	$f_{measured}$ (MHz)	% Error
0.1	0.02	5904	6000	5892	1.6
0.2	0.04	5897	6000	5949	1.72
0.3	0.06	5910	6000	6105	1.5
0.4	0.08	5884	6000	5967	1.93

4. CONCLUSIONS

The ANN model for shorted RMSA over a wide frequency range and substrate thickness increasing from 0.04 to $0.1\lambda_0$, is proposed. The neural network model is developed using parameters like, substrate thickness, dielectric constant, resonance frequency and an edge extension length in terms of substrate thickness. The predicted patch side length as obtained from the neural network model which when simulated using IE3D software gives closer match with the desired patch resonance frequency over varying substrate thickness. Further the measurements were carried out to validate the simulated results. The measured results are in close agreement with predicted and simulated values. In the world of miniaturization, compact shorted MSAs are widely used. The closer form expressions to calculate shorted patch length in compact MSAs is not available. Thus the proposed model can be used to design shorted RMSA on thicker substrate and at any given frequency. In the future work, similar neural network model will be developed to accurately calculate the edge extension length / shorted patch length in compact variations of circular and equilateral triangular MSA. Also the ANN models will be developed to predict the length of shorted MSAs on suspended dielectric substrates.

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