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Resonant frequency of circular microstrip antenna using artificial neural networks

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A novel method of using artificial neural networks (ANNs) for the calculation of the resonant frequency of electrically thick and thin circular microstrip patch antenna has been adopted in this paper. It is useful for the computer-aided design (CAD) of microstrip antennas. The results obtained using ANNs are compared with the measured and calculated values reported by other authors. The theoretical resonant frequency values obtained using ANNs are in very good agreement with measured and calculated values reported by other researchers.

Keywords: Resonant frequency; Circular microstrip antenna; Microstrip antenna, Genetic algorithms; Artificial neural networks

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1 Introduction

Microstrip antennas are one of the most popular type antennas, since they are lightweight, have simple geometries, are inexpensive to fabricate and can easily be made conformal to the host body. These attractive features have increased the application of microstrip antennas recently and stimulated greater efforts to investigate their performances[1-4]. In a circular microstrip antenna designing, it is important to determine the resonant frequency of the antenna accurately, because the antenna has narrow bandwidth and can only operate in the vicinity of the resonant frequency[5]. A number of methods are available to determine the resonant frequency of circular patch antenna, as this is one of the most popular and convenient shapes[4-8,9,10-13]. However, most of the previous theoretical and experimental work was carried out only with electrically thin microstrip antennas, normally of the order of $h/\lambda_d \leq 0.02$, where h is the thickness of the dielectric substrate and λ_d the wavelength in the substrate. In this paper, an attempt has been made to exploit the capability of artificial neural networks to calculate the resonant frequency of the electrically thin and thick circular microstrip patch antennas.

2 Resonant frequency of a circular microstrip antenna

The resonant frequency of a circular disc microstrip antenna for the TM_{nm} mode is given by

$$f_{nm} = \frac{k_{nm} c}{2\pi a \sqrt{\varepsilon_r}} \quad \dots (1)$$

where k_{nm} is the mth zero of derivative of the Bessel function of order n, c the velocity of electromagnetic waves in free space, $\in_r$ the relative dielectric constant of the substrate, and a the physical radius of circular patch (Fig. 1). The dominant mode is TM_{11} ($n = m = 1$), for which $k_{11} = 1.84118$. The TM_{11} mode of the circular microstrip patch is widely used in microstrip antenna applications.

Equation (1) is based on the assumption of a perfect magnetic wall and neglects the fringing fields at the open-end edges of the microstrip patch. It is commonly suggested that the radius a in Eq. (1) be replaced by an effective patch radius a_{eff}, which is slightly larger than the physical radius a, taking in to account the influence of fringing fields at the edges and dielectric in homogeneity. The effective patch radius expression to be found must be larger than a,

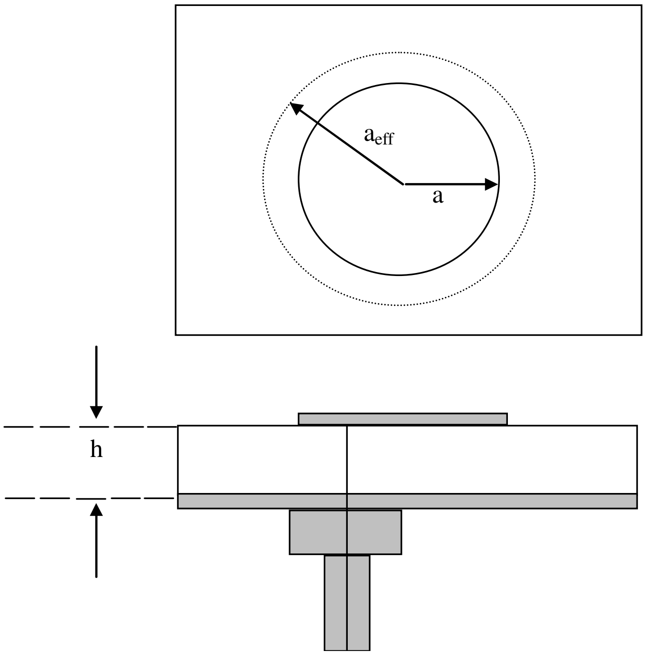

Fig.1 — Geometry of circular microstrip antenna

and depends on *a*, permittivity and thickness of substrate.

3 The back propagation algorithm

The neural network learns from the examples by constructing the input-output mapping. The learning process of a neural network for obtaining a nonlinear mapping can be seen as a function approximation problem. Consider the functional relationship described by[14-16]

$$\mathbf{d}=f(\mathbf{x}) \qquad \ldots (2)$$

where the vector **x** is the input and the vector **d** is the output. The vector-valued function *f* (.) is assumed to be unknown. To make up for the lack of knowledge about the function *f* (.), one can take the set of labeled examples:

$$F=\{(x_i d_i)\} \qquad \ldots (3)$$

where $i = 1 \ldots N$

The requirement is to design a neural network that approximates the unknown function *f* (.) such that *F* (.) describing the input-output mapping actually realized by the network is close enough to *f* (.) over all the inputs, as given by

$$|F(\mathbf{x})-f(\mathbf{x})| \, \pi \, e \text{ for all } \mathbf{x} \qquad \ldots (4)$$

where, *e* is a small positive number. If the size of training set is large enough and the network is equipped with adequate number of free parameters, then the approximate error *e* can be made small enough for the task[17]. The approximation problem described here is a perfect case for supervised learning with physical radius of the circular patch, thickness of dielectric substrate and the relative permittivity of the substrate becoming the input vector and resonant frequency being taken as desired response. Neural Network model helps realizing the proposed model as multiple-input-single-output system.

A multilayer perceptron (MLP) trained with the back propagation algorithm is considered for performing a nonlinear input-output mapping. The back propagation algorithm based on generalized delta rule is given as[18-19]

$$\Delta w_{ji}(n)=\alpha\Delta w_{ji}(n-1)+\eta\delta_i(n)y_i(n) \qquad \ldots (5)$$

where, $\Delta w(n)$ is change in weight at time *n* as compared to the weight $\Delta w(n-1)$ at time $(n-1)$, α the momentum constant, δ the local gradient, η the learning parameter, *y* the output generated by a neuron and *i,j* represent the position of neuron in the network.

The main concern with approximation problems using ANNs as input-output mapping, is to first determine number of hidden layers in multilayer perceptron and then number of nodes in hidden layers. The practical way to find out a suitable structure is to start with a minimal structure network and periodically perform validation along with the training operation. In case of not so satisfactory results, adding new hidden layers and neurons may enlarge the structure.

4 Application of genetic algorithm to the problem

Genetic algorithm is a parallel, robust and probabilistic search technique that is simple and easily implemented without gradient calculation, compared with the conventional gradient-based search procedure. Most important of all, the genetic algorithm also provides a mechanism for global search that is not easily trapped in local optima[20]. A basic genetic algorithm consists of five components. These are a random number generator, a fitness evaluation unit and genetic operators for reproduction, crossover and mutation operations[5,9]. Akdagli and Gunney[5] have proposed the model for effective patch radius expression for calculation of the resonant frequencies of both electrically thin and thick circular microstrip antenna. Since the resonant frequency depends strongly on the effective patch radius a_{eff} , first a modal for the effective patch radius expression was chosen, and then the unknown coefficient's values were obtained by a genetic algorithm.

The effective patch radius of a circular microstrip patch is determined by the relative dielectric constant of the substrate $\in_r$, the physical radius *a* and the thickness of the substrate *h*. Therefore, the effective patch radius a_{eff} is larger than *a* and depends on $\in_r$, *a* and *h*.

The following modal for the effective patch radius expression, which produces good results was chosen.

$$a_{\text{eff}} = a + h(\beta_1 + \beta_2)\left[\left(\frac{h}{a}\right)^{\beta_3} + \left\{\frac{1}{\varepsilon_r}\right\}^{\beta_4}\right] \quad \ldots (6)$$

where the unknown coefficients β_1, β_2, β_3 and β_4 are determined by a genetic algorithm. The unknown coefficient values of the model given by Eq. (6) are optimized by the genetic algorithm and the coefficients values are

$$\beta_1 = 0.247,\ \beta_2 = 610.731,\ \beta_3 = 8.690,\ \beta_4 = 8.152 \quad \ldots (7)$$

Thus, the model derived from Genetic Algorithm (GA) for effective patch radius expression a_{eff} is given as

$$a_{\text{eff}} = a + h\left(0.247 + 610.731\left[\left(\frac{h}{a}\right)^{8.690} + \left\{\frac{1}{\varepsilon_r}\right\}^{8.152}\right]\right) \quad \ldots (8)$$

The resonant frequencies are then calculated by the formula

$$f_{\text{nm}} = \frac{k_{\text{nm}}c}{2\pi a_{\text{eff}}\sqrt{\varepsilon_r}} \quad \ldots (9)$$

Thus the resonant frequency of a circular microstrip antenna for different *a*, *h* and $\in_r$ were calculated using Eq. (9). The data thus obtained (which is given in Table 1) have been used for developing a feed forward neural network model.

5 Development of model

The ability and adaptability to learn, a generalizability, small information requirement, fast real-time operation, and ease of implementation features have made ANNs popular among the researchers for various applications. In this paper, ANNs have been implemented to address the problem of accurate determination of resonant frequency of circular microstrip patch antenna. The back-propagation algorithm, a gradient decent algorithm, is

Table 1 — Resonant frequencies for different values of *a*, *h* and $\in_r$ obtained from the model derived from Genetic Algorithm

Physical Radius of Circular Patch *a*, cm	Thickness of dielectric substrate *h*, cm	Relative permittivity of substrate $\in_r$	Resonant Frequency f_{GA}, MHz
13.762	1.28	2.70	374
13.63	1.27	2.70	377
1.003	0.1633	2.32	5028
13.499	1.27	2.70	381
1.134	0.1633	2.32	4513
1.266	0.08	2.59	4181
7.185	0.318	2.32	773
1.397	0.08	2.59	3800
7.053	0.318	2.32	787
1.529	0.08	2.59	3480
1.923	0.2347	4.56	2078
6.79	0.1633	2.32	932
2.055	0.2347	4.55	1950
6.659	0.08	2.32	858
2.186	0.2347	4.55	1836
6.527	0.08	2.32	875
2.318	0.2347	4.55	1734
5.606	0.1633	2.32	1004
2.976	0.2347	4.55	1358
5.475	0.1633	2.32	1027
3.107	0.2347	4.55	1302
5.343	0.1633	2.32	1052
3.502	0.318	2.5	1506
5.212	0.1633	2.32	1077
3.633	0.318	2.5	1455
5.08	0.1633	2.32	1104
3.765	0.1514	2.50	1442
4.949	0.2347	4.55	823
3.896	0.1514	2.5	1395
4.028	0.2347	4.55	1008
4.686	0.318	2.52	1138
4.166	0.2347	4.55	976
4.554	0.318	2.52	1169
6.8	0.318	2.32	815
3.493	0.1588	2.50	1550
1.27	0.0794	2.59	4168
1.04	0.235	4.55	3750
0.77	0.235	4.55	4945
1.15	0.15875	2.62	4413
1.07	0.15875	2.625	4722
0.96	0.15875	2.65	5224
0.74	0.15872	2.65	6636
0.82	0.15875	2.65	6043
13.894	1.27	2.70	371
6.8	0.08	2.32	840

used for training the network in a supervised manner. Three-layer neural networks with structure 3-15-5 have been used (Fig. 2). Other parameters considered in the network are as follows

Learning rate parameter = 0.9
Momentum factor =0.5
Normalized system error = 0.00001

The training was performed using 45 data sets comprising of physical radius of circular patch, thickness of dielectric substrate and relative permittivity of substrate as input and resonant frequency as output. The network was trained to the extent of good convergence conditions. The developed neural network model was tested for 8 test input resonant frequencies derived over the entire range of physical radius, thickness of dielectric and relative permittivity of substrate by taking those values, which are not included in the training. The calculated resonant frequencies obtained with proposed model are shown in Table 2 along with the measured and calculated resonant frequencies reported by other researchers[1,4-8,10-13,21-22]

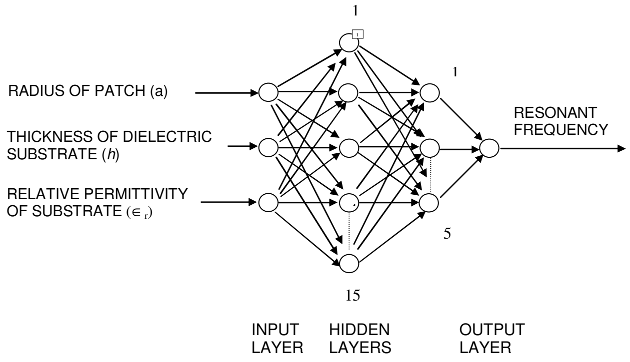

Fig. 2 — Structure of the developed neural network model

6 Results and discussion

It can be seen from Table 2 that the network is capable of approximating the input-output relationship for dependent parameter resonant frequency with independent parameters, such as radius of circular patch, thickness of dielectric and relative permittivity of substrate. The developed neural network model is tested for calculation of resonant frequencies by taking the values of physical radius, thickness of dielectric and relative permittivity of substrate not included in the training. The

Table 2 — Comparison of measured and calculated resonant frequencies of circular microstrip antenna

Parameter	Values							
a, cm	5.000	3.800	4.850	3.493	4.950	3.975	2.990	2.000
h, cm	0.1590	0.1524	0.3180	0.3175	0.2350	0.2350	0.2350	0.2350
∈ **r**	2.32	2.49	2.52	2.50	4.55	4.55	4.55	4.55
h/λ	0.009106	0.011567	0.018493	0.025268	0.017210	0.017210	0.022724	0.033468
f_{me}, MHz [measured] [Ref. 6,1,4,21]	1128 [Ref. 8]	1443 [Ref. 6]	1099 [Ref. 3]	1510 [Ref. 3]	825 [Ref. 1]	1030 [Ref. 1]	1360 [Ref. 1]	2003 [Ref. 1]
$f_{\text{proposed model}}$, MHz	1117	1432	1104	1514	821	1022	1355	2005
f_{ak}, MHz [Ref. 5]	1123	1432	1100	1510	823	1022	1352	2002
f_{ca}, MHz [Ref. 4]	1141	1445	1115	1539	818	1014	1339	1972
f_{ho}, MHz [Ref. 22]	1154	1466	1142	1580	833	1037	1379	2061
f_{de}, MHz [Ref. 7]	1127	1427	1098	1513	818	1016	1344	1990
f_{ab}, MHz [Ref. 6]	1133	1436	1105	1522	827	1027	1358	2009
f_{li}, MHz [Ref. 11]	1136	1439	1109	1529	827	1027	1360	2012
f_{ro}, MHz [Ref. 13]	1124	1423	1095	1509	816	1013	1340	1984
f_{gu}, MHz [Ref. 8]	1132	1435	1105	1523	825	1026	1359	2012
f_{le}, MHz [Ref. 12]	1125	1423	1091	1498	817	1013	1336	1966
f_{ku}, MHz [Ref. 10]	1133	1436	1105	1522	827	1027	1358	2009

Table 3 — Average percentage errors

Resonant Frequency	Error, %
$f_{\text{proposed model}}$	0.51
f_{ak} [Ref. 5]	0.36
f_{ca} [Ref. 4]	1.21
f_{ho} [Ref. 22]	2.36
f_{de} [Ref. 7]	0.68
f_{ab} [Ref. 6]	0.40
f_{li} [Ref. 11]	0.51
f_{ro} [Ref. 13]	0.97
f_{gu} [Ref. 8]	0.39
f_{le} [Ref. 12]	1.17
f_{ku} [Ref. 10]	0.40

calculated values thus obtained are shown in Table 2. Further the calculated values thus obtained, are compared with the theoretical and experimental values reported by other investigators, which are all shown in Table 2. The entries of f_{me}, $f_{\text{proposed model}}$, f_{ak}, f_{ca}, f_{ho}, f_{de}, f_{ab}, f_{li}, f_{ro}, f_{gu}, f_{le}, and f_{ku} represent, the values measured[1, 4,6,21] and calculated by the proposed model[4-8,10-13,22], respectively. The average percentage error for every method is also listed in Table 3. The theoretical resonant frequency values obtained using ANNs are in very good agreement with measured and calculated values reported by other researchers. This close agreement supports the validity of the proposed model.

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