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Artificial Neural Network to Design of Circular Microstrip Antenna

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ARTIFICIAL NEURAL NETWORK TO DESIGN OF CIRCULAR MICROSTRIP ANTENNA

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Artificial Neural Network to Design of Circular Microstrip Antenna

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Abstract - A simple design to compute accurate resonant frequencies of circular microstrip antennas using artificial neural networks. (ANN) is proposed. ANN model is developed to calculate the antenna dimensions for the given resonant frequency, dielectric constant and height of substrate. ANN is designed using radial basis function networks. The results show better agreement with the trained and tested data of ANN models. The results are verified by the experimental results to produce accurate ANN models. This presents ANN model practically as an alternative method to the detailed electromagnetic design of circular microstrip antenna. We have also used a simulator to validate the present model.

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I. INTRODUCTION

In high-performance spacecraft, aircraft, missile and satellite applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, and low profile antennas may be required. Presently, there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet these requirements, microstrip antennas can be used [1]. These antennas are low-profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when particular patch shape and mode are selected they are very versatile in terms of resonant frequency, polarization, pattern, and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern can be adjusted [2]. Often microstrip antennas are also referred to as patch antennas because of the radiating elements (patches) photo etched on the dielectric substrate. This radiating patch may be square, rectangular, circular, elliptical, triangular, and any other configuration. In this work, circular microstrip antennas are the ones under consideration "Fig. 1"

The patch dimensions of circular microstrip antennas are usually designed so its pattern maximum is normal to the patch. Because of their narrow

bandwidths and effectively operation in the vicinity of resonant frequency, the choice of the patch dimensions giving the specified resonant frequency is very important. In the literature, artificial neural network (ANN) models have been built usually for the analysis of microstrip antennas in various forms such as rectangular, circular, and equilateral triangle patch antennas [3-7]. In this formulation, two points are especially emphasized: the resonant frequency of the antenna and the condition for good radiation efficiency. Using reverse modeling, an analysis ANN is built to find out the resonant frequency immediately for a given circular microstrip antenna system. The models are simple, easy to apply, and very useful for antenna engineers to predict both patch dimensions and resonant frequency. Thus, in the following sections, the forward and reverse sides of this design problem are defined as black-ANN boxes; then the electromagnetic background is briefly summarized for building the synthesis ANN model. In the following section, also, this synthesis model is reversed for the analysis purpose of the given antenna system whose results are compared with those in the literature.

II. RESONANT FREQUENCY OF CIRCULAR MICROSTRIP ANTENNA

The formula for the resonant frequency of a circular microstrip disk antenna obtained from the cavity model with perfect magnetic wall is given in [6]. For the present paper, a simple formula was given as

$$f_{r, nm} = \frac{X_{nm} C}{2\pi a \sqrt{\epsilon_{dyn}}} \quad (1)$$

Where X_{nm} is the m^{th} root of the equation $J_n(X_{nm})=0$, C is the velocity of light in free space, a is the patch radius, and ϵ_r is relative dielectric constant.

In order to include fringe field effects, the patch radius (a) in (1) must be replaced with its effective value. Several expressions have been used to represent the effective disk radius [8-10]. The most preferred one of these was produced from the static fringe capacitance expression of *Chew* and *Kong* [10] to be valid for $d/a \leq 0.5$ and $\epsilon_r \leq 10$

$$a_{e_f} = \left\{ a^2 + \frac{2da}{\pi\epsilon_r} \left[\ln\left(\frac{a}{2d}\right) + (1.41\epsilon_r + 1.77) + \frac{d}{a}(0.268\epsilon_r + 1.65) \right] \right\}^{\frac{1}{2}} \quad (2)$$

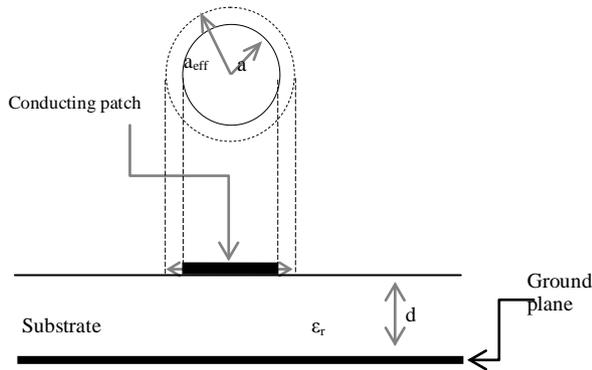


Figure 1 : Geometry of circular microstrip patch.

The results of the previous studies based on the cavity model show that effective values for both patch radius and substrate permittivity must be used to obtain better results in the resonant frequency calculations of the circular disk microstrip structure. In this analysis, extra improvement over the previously presented results in literature is obtained by replacing the effective permittivity with the dynamic one which correctly includes the modal field variation and the fringe field effects.

Dynamic permittivity of the structure can be defined as

$$\epsilon_{dyn} = \frac{C(a, d, \epsilon)}{C(a, d, \epsilon_0)} \quad (3)$$

Where $C(a, d, \epsilon)$ is the total capacitance of the dominant mode TM^{11} which we can calculate $C(a, d, \epsilon)$ as

$$C(a, d, \epsilon) = \frac{0.8525\epsilon_0\epsilon_r\pi a^2}{d} + 0.5C_{fring} \quad (4)$$

Where the first term is the main capacitance and the second term is the fringing capacitance. As shown in previous works [10-12], accuracy of the formula for the resonant frequency can be improved with a better approximation for the fringing capacitance C_{fring}

$$C_{fring} = 2a\epsilon_0 \left[\ln\left(\frac{a}{2d}\right) + (1.41\epsilon_r + 1.77) + \frac{d}{a}(0.268\epsilon_r + 1.65) \right] \quad (5)$$

Substituting (4) into (5) yields the total capacitance for the resonant frequency.

$$C(a, d, \epsilon) = \frac{0.8525\epsilon_0\epsilon_r\pi a^2}{d} + a\epsilon_0 \left[\ln\left(\frac{a}{2d}\right) + (1.41\epsilon_r + 1.77) + \frac{d}{a}(0.268\epsilon_r + 1.65) \right] \quad (6)$$

$$C(a, d, \epsilon_0) = \frac{0.8525\epsilon_0\pi a^2}{d} + a\epsilon_0 \left[\ln\left(\frac{a}{2d}\right) + (1.41 + 1.77) + \frac{d}{a}(0.268 + 1.65) \right] \quad (7)$$

Where $\epsilon_0 = (1/36\pi \times 10^9 \text{ Fm}^{-1})$ is the dielectric constant of vacuum

In the following section, a basic artificial neural network used in this paper is described briefly and the application of neural networks to the calculation of the resonant frequency of a microstrip antenna is then explained.

III. DESIGN PROBLEM FOR THE MICROSTRIP ANTENNA

In this work, the patch geometry of the microstrip antenna is obtained as a function of input variables, which are height of the dielectric material (d), dielectric constants of the substrate (ϵ_r), and the resonant frequency (f_r), using ANN techniques "Fig. 2". Similarly, in the analysis ANN, the resonant frequency of the antenna is obtained as a function of patch dimensions (a), height of the dielectric substrate (d), and dielectric constants of the material (ϵ_r) "Fig. 3". Thus, the forward and reverse sides of the problem will be defined for the circular patch geometry in the following subsections.

a) *The forward side of the problem: The synthesis ANN*

The input quantities to the ANN black-box in synthesis "Fig. 2" can be ordered as:

- d : height of the dielectric substrate;
- ϵ_r : dielectric substrate.
- f_r : resonant frequency of the antenna.

The following quantities can be obtained from the output of the black-box as functions of the input variables:

- a : radius of the patch;



Figure 2 : Synthesis of ANN model.

b) *The reverse side of the problem: The analysis ANN*

In the analysis side of the problem, terminology similar to that in the synthesis mechanism is used, but

the resonant frequency of the antenna is obtained from the output for a chosen dielectric substrate and patch dimensions at the input side as shown in "Fig. 3"



Figure 3: Analysis of ANN model.

IV. ANN MODELING

Feed forward neural networks with a single hidden layer that use radial basis activation functions for hidden neurons are called radial basis function networks. RBF networks are applied for various microwave modeling purposes. Commonly used radial basis activation functions are Gaussian and multiquadratic. [13]

The training and test data of the synthesis and analysis ANN were obtained from both experimental results given in previous works [3-12] and are generated by application of "Eq. (1)". The data are in matrix form consisting of inputs and target values and arranged according to the definitions of the problem. The RBF network which has a configuration of, 5 inputs and 1 output were used for the analysis ANN and 5 inputs and 1 output for the synthesis ANN, the spread value was chosen as 0.01, which gives the best accuracy.

V. SIMULATION AND RESULTS

In synthesis and analysis, RBF network were the one giving the best approximation to the target values whose structure is defined in the following subsection. The results of the synthesis and analysis ANN for an isotropic material and comparison with the targets are given in Table.1, and 2. The agreement with the measured values is good and corresponding percentage error values are small in almost all the cases

Table 1 : Results of the synthesis ANN and comparison with the targets.

d (mm)	ϵ_r	f_r (GHz)	a-Target (mm)	a-RBF (mm)	Errors
1.588	2.5	1.57	34.93	34.9673	-0.0373
3.175	2.5	1.51	34.93	34.9307	-0.0007
2.35	4.55	0.825	49.5	49.5836	-0.0836
2.35	4.55	1.03	39.75	39.6348	0.1152
2.35	4.55	1.36	29.9	30.0264	-0.1264
2.35	4.55	2.003	20	20.0767	-0.0767
2.35	4.55	3.75	10.4	10.4153	-0.0153
2.35	4.55	4.945	7.7	7.6955	0.0045
1.5875	2.65	4.425	11.5	11.5655	-0.0655
1.5875	2.65	4.723	10.7	10.6224	0.0776
1.5875	2.65	5.224	9.6	9.5966	0.0034
1.5875	2.65	6.074	8.2	8.1851	0.0149
1.5875	2.65	6.634	7.4	7.4028	-0.0028

Table 2 : Analysis of computed, measured & ANN predicted resonant frequencies

Physical and Electrical Parameters			f_r (GHz) measured	Calculated Frequencies f_r (GHz)				Our results (GHz) f_r^{11} -RBF	Measured By
d (mm)	ϵ_r	a (mm)		[14]	[17]	[18]	[16]		
1.588	2.5	34.93	1.57	1.592	1.555	1.559	1.570	1.580	[14]
3.175	2.5	34.93	1.51	1.592	1.522	1.529	1.547	1.509	
2.35	4.55	49.5	0.825	0.832	0.827	0.827	0.824	0.821	[17]
2.35	4.55	39.75	1.03	1.037	1.027	1.027	1.023	1.014	
2.35	4.55	29.9	1.36	1.378	1.358	1.360	1.355	1.377	
2.35	4.55	20	2.003	2.060	2.009	2.012	2.007	2.026	
2.35	4.55	10.4	3.75	3.962	3.743	3.737	3.752	3.787	
2.35	4.55	7.7	4.945	5.352	4.938	4.924	4.945	4.943	
1.5875	2.65	11.5	4.425	4.695	4.414	4.438	4.418	4.529	[15]
1.5875	2.65	10.7	4.723	5.046	4.724	4.750	4.727	4.784	

1.5875	2.65	9.6	5.224	5.625	5.228	5.258	5.228	5.290	
1.5875	2.65	8.2	6.074	7.297	6.049	6.086	6.043	6.087	
1.5875	2.65	7.4	6.634	6.585	6.646	6.687	6.634	6.636	

The simulation of circular microstrip antenna is done on HFSS software and we get simulation results of return loss, VSWR, polar plot of E- fields and plot of 3D E-fields [HFSS]. Fig. 4. shows the circular microstrip antenna with probe feed. In fig.5 shows the plot of return loss and VSWR. Fig.6. shows the polar plot of E- fields and plot of 3D E-fields.

The figure (4) shows the proposed circular patch antenna using the Ansoft-HFSS.

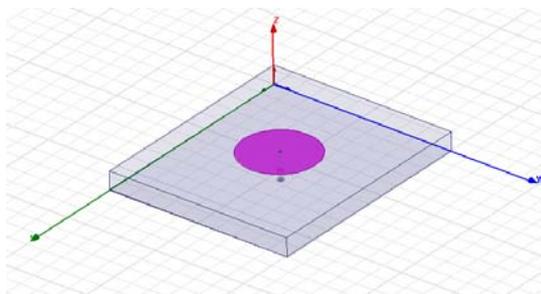


Figure 4 : Circular patch antenna showing the position of probe feed from HFSS simulation tool display.

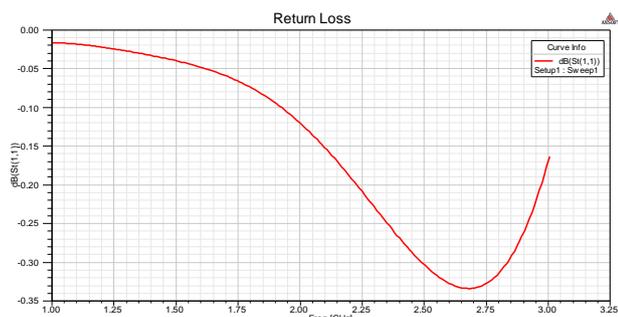


Figure 5 : Shows the plot of return loss and VSWR.

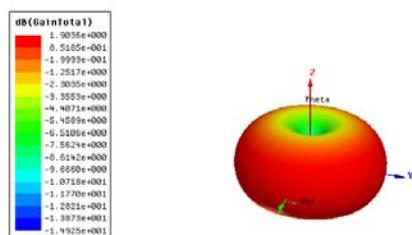


Figure 6 : Shows the plot of 3D E-fields.

VI. CONCLUSION

In this design procedure, synthesis is defined as the forward side and then analysis as the reverse side of the problem. Therefore, one can obtain the geometric dimensions with high accuracy, which is the

radius of the patch in our geometry, at the output of the synthesis network by inputting resonant frequency, height and dielectric constants of the chosen substrate. In this work, the analysis is considered as a final stage of the design procedure, therefore the parameters of the analysis ANN network are determined by the data obtained reversing the input-output data of the synthesis network. Thus, resonant frequency resulted from the synthesized geometry is examined against the target in the analysis ANN network. Finally, in this work, a general design procedure for the microstrip antennas and filter is suggested using artificial neural network.

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