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Analysis of Resonant Characteristics and Radiation Patterns of a Circular Microstrip Antenna on Isotropic or Uniaxially Anisotropic Substrate Using Artificial Neural Network

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***Abstract*— In this work a single neural network for determining the resonant frequency, quality factor and far-zone radiation patterns of a circular disk microstrip antenna, printed on a uniaxial anisotropic substrate using effective parameters in conjunction with spectral dyadic Green's function. The resonant frequency results predicted by the numerical results show that there are substantial deviations in calculated resonant frequency and quality factor when substrate dielectric anisotropy is considered. Furthermore, significant variations are seen in the radiation patterns of the structures due to substrate anisotropy. The variations of resonant frequency, quality factor and radiation patterns of the structure, with respect to anisotropy ratio of the substrate, for several values of substrate thickness and patch radius are presented.**

Key-Words— Circular microstrip antenna, effective parameters, uniaxial anisotropic, artificial neural networks.

I. INTRODUCTION

During the last three decades, a considerable number of papers have been published on the performance and applications of microstrip patch antennas. These patch antennas possess many desirable features, that make this type of antennas useful for many applications in radar and wireless communication systems. Various patch configurations implemented on different types of substrates have been tested and investigated. In practice, it was found that the choice of the substrate material is of a great importance and plays a significant role in achieving the optimum radiation characteristics of the antenna.

Some substrate materials used for integrated microwave circuits or printed antennas exhibit dielectric anisotropy. This phenomenon occurs either naturally in the material or is introduced during the manufacturing process. In addition, anisotropic substrates have become popular in the design of microwave integrated circuit components and microstrip antennas [1-7]. Uniaxial substrates have drawn more attention due to their availability in materials such as sapphire, boron nitride and E-10 ceramic-impregnated Teflon. Previous studies of anisotropic materials used in microwave devices indicate that the effects of anisotropy on the performance of such structures particularly in high frequencies cannot be ignored [1, 5, 6]. Furthermore, it has been shown that the performance of directional couplers can be improved by using the anisotropic substrates to equalize the even and odd mode phase velocities [2]. Therefore, many investigations are examining the effects of substrate anisotropy in microwave components performance.

However, we are interested in this work to study the effects of anisotropic substrate materials on the resonant frequency and radiation field of a circular patch antenna. Moreover the study of this type of substrates is of interest, many practical substrates have a significant amount of anisotropy that can affect the performance of printed circuits and antennas, and thus accurate characterization and design must account for this effect [1]. It is found that the use of such materials may have a beneficial effect on circuits or Antennas [2, 3]. Therefore, many investigations are examining the effects of substrate anisotropy in microwave components performance.

Circular microstrip patch resonators can be used either as radiating antennas or as oscillators and filters in microwave integrated circuits (MIC's) [8]. In some applications such as arrays, circular geometry of the patch offers certain advantages over other configurations. The experimental results have shown that circular microstrip elements could be easily modified to produce a range of impedances, radiation patterns and frequencies of operation [9]. The studies on circular patch microstrip antennas with anisotropic substrate are in limited number [10-13].

In this work, we have demonstrated the force of neural network approach in antenna modeling using ANN combined with EM knowledge to develop a single neural network model for the calculation of resonant frequency of circular patch antenna printed on isotropic or uniaxially anisotropic substrate. The idea is to determine effective parameters for the antenna and to use these parameters in Green's function of a single layer isotropic substrate to give results closer as possible to ones given with the appropriate Green's function.

II. THEORY

Calculating resonant frequency of a circular patch printed on isotropic substrate requires three inputs, which are the patch dimensions a, the substrate height h and its relative permittivity ε_r. Time involved in the spectral domain approach to generate training, test, and validation matrices is very large, then we use the model of the Ref [14] to generate data base By the same way, if we want to take the substrate uniaxial anisotropy's into account, the relative dielectric permittivity ε_r will be replaced with the tensor $\varepsilon_r = diag(\varepsilon_x, \varepsilon_x, \varepsilon_z)$ where ε_x and ε_z are the relative dielectric permittivity along x and z axis, respectively, (Fig. 1).

For the case of uniaxially anisotropic substrate, ε_{re} given in [17] there resulting values are:

$$\varepsilon_e = \varepsilon_z \quad (1)$$

$$h_e = h\sqrt{\frac{\varepsilon_x}{\varepsilon_z}} \quad (2)$$

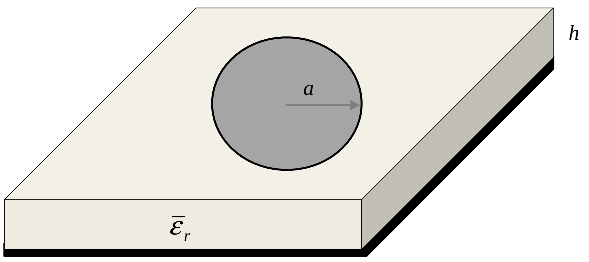


Figure 1. Geometry of circular microstrip antenna printed on anisotropic substrate.

With the increase of design parameter's number, the network size increases, increasing the size of training set required for proper generalization. Because of the different natures of the additional parameters, data generation becomes more complicate (Fig. 2), an alternative to the conventional approach is required.

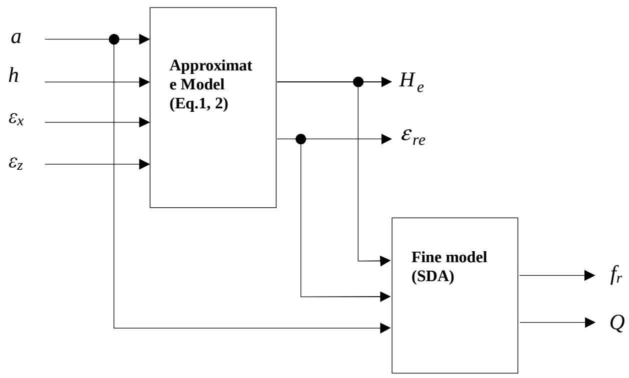


Figure 2. Data generation model combined with EM knowledge trained with SDA responses for the calculation of resonant frequency and quality factor of circular patch antenna printed on uniaxially anisotropic substrate.

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

III. ANN Modeling

Electromagnetic knowledge combined with artificial neural network is proposed to solve this problem. Effective dielectric constant and height are determined for the case uniaxially anisotropic substrate (Fig. 3). Used in Green's function, effective parameters give results closer to ones computed using the appropriate Green's function. In this work, both Multilayer Perceptron (MLP) networks are used in ANN models. The structures of these ANNs are described briefly below.

A. Multilayer Perceptron Networks

MLP neural networks trained with the standard back propagation algorithm. They are supervised networks and so they require a desired response to be trained. They learn how to transform input data into a desired response, and so they are widely used for pattern classification. With 1 or 2 hidden layers, they can approximate virtually any input-output map. They have been shown to approximate the performance of optimal statistical classifiers in difficult problems. Most neural network applications involve MLP. The basic MLP 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 (usually sigmoid). In a multilayer perceptron, the outputs of the units in one layer form the inputs to the next layer. The weights of the network are usually computed by training the network using the back propagation algorithm [12].

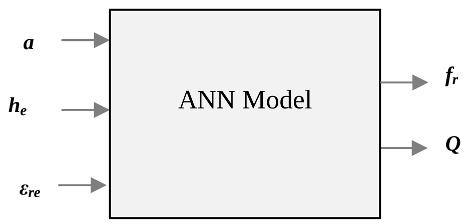


Figure 3. Neural model for calculating the resonant frequency and quality factor of circular microstrip antenna with effective parameters.

B. Structures of the Neural Networks

The MLP network, which has a configuration of 4 input neurons, 12 and 8 neurons in 2 hidden layers, and 2 output neuron with learning rate =0.1, goal = 0.0001, was trained for 10000 epochs. Hyperbolic tangent sigmoid and linear transfer functions were used in MLP training. MLP models were trained with almost all network learning algorithms. Using [15], two are generated for learning and testing the neural model. The different network input and output parameters are shown in Figure 2. As it is shown in this figure, the EM knowledge in form of empirical functions, given by (1) and (2) for the case of uniaxial anisotropic substrate, is used to preprocess the ANN model inputs. Some strategies are adopted to reduce time of training and ameliorate the ANN model accuracy, such as preprocessing of inputs and output, randomizing the distribution of the learning data [15-16], and resampling with a smaller discretization step in the part of input space corresponding to an unacceptably high error (small antenna parameters give large variation in the resonant frequency).

IV. Results

In this section we have compared our computed values with different theorical and experimental values available in open literature.

Table I and II compares our results calculated by ANN model with the results measured and calculated in the literature, These comparisons indicate excellent agreements for isotropic substrate case.

"Fig. 4" depicts that the variation of dominant mode resonant frequency with the variation of patch radius (*a/h*). The antenna parameters for this studies are *h*=0.49mm, $\varepsilon_r = 2.43$.

TABLE. I THEORICAL AND EXPERIMENTAL VALUES OF RESONANT FREQUENCY FOR THE DOMINANT MODE OF CIRCULAR PATCH ANTENNA, $h = 1.5875mm$, $\varepsilon_r = 2.65$.

a (mm)	a/h	Experiment (GHz) [20]	Computed (GHz)			
			[19]	*[18]*	*[17]*	*Present*
11.5	7.244	4.425	4.609	4.576	4.39	4.443
10.7	6.740	4.723	4.938	4.903	4.70	4.730
9.6	6.047	5.224	5.473	5.436	5.20	5.272
8.2	5.165	6.074	6.346	6.307	6.01	6.055
7.4	4.661	6.634	6.981	6.941	6.595	6.678

TABLE II. COMPARISON OF THE EXPERIMENTAL RESULTS IN [10] WITH THE RESULTS OF THE NUMERICAL METHOD OF THIS PAPER FOR THE RESONANT FREQUENCY OF THE FUNDAMENTAL MODE OF A CIRCULAR MICROSTRIP PATCH ON A SINGLE LAYER ISOTROPIC DIELECTRIC SUBSTRATE OF PERMITTIVITY $\varepsilon_r = 2.43$ AND THICKNESS $h = 0.49mm$.

a (mm)	a/h	Experiment (GHz) [10]	Computed (GHz)		
			[21]	*[22]*	*Present*
1.9698	4.02	25.60	25.90	25.736	25.65
3.9592	8.08	13.10	13.25	13.331	13.28
5.8898	12.02	8.960	9.032	9.111	9.010
8.0017	16.33	6.810	6.831	6.775	6.816
9.9617	20.33	5.470	5.515	5.475	5.503

Here we have compared our computed values with the measurements done by [10]. This plot indicates that the present model shows excellent agreements with the measurements for all values of patch radius.

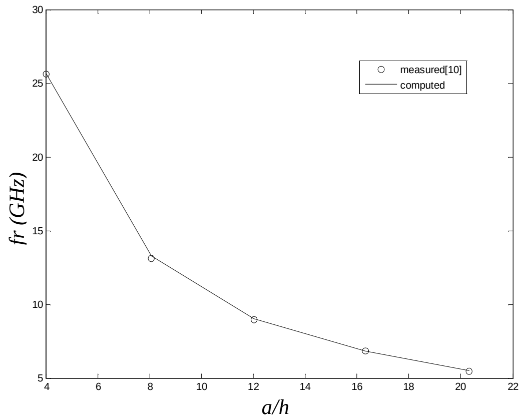
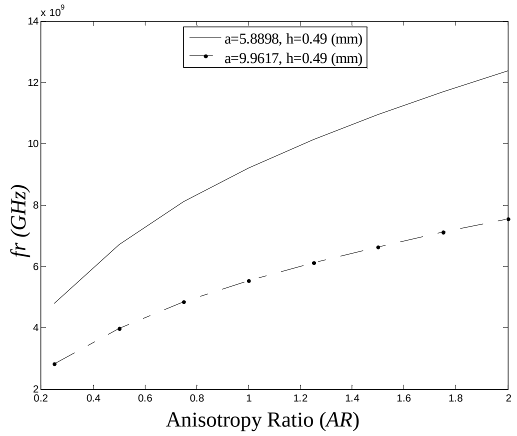


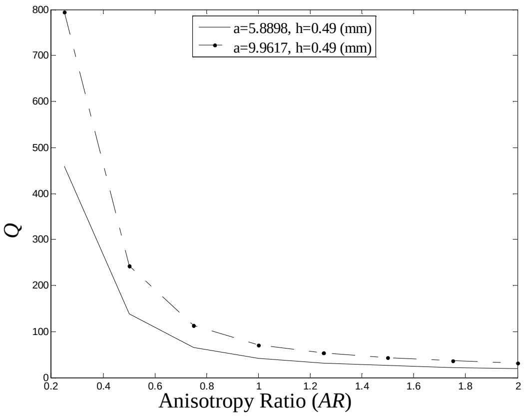
Figure 4. Theoretical and experimental variation of dominant mode resonant frequency as a function of patch radius(*a/h*). Parameters as in table II.

In "Fig. 5" the effect of uniaxial anisotropy on the resonant frequency, quality factor and radiation pattern of the structure is analyzed. The anisotropy ratio (*AR*) is defined as $AR = \varepsilon_x / \varepsilon_z$

Fig. 5(a) represents resonant frequency of the fundamental mode versus anisotropy ratio for a circular patch printed on a uniaxial substrate at different values of patch radius and substrate thickness. As anisotropy ratio changes from 0.25 to 2, the anisotropy effect on the resonant frequency cannot be ignored and must be taken into account in the design procedure. In addition, the resonant frequency reduction could be used for reducing the radiating element size or attending desired directivity as shown later. We can conclude that the permittivity ε_z along the optical axis is the significant and most important factor in determining of the resonant frequency.

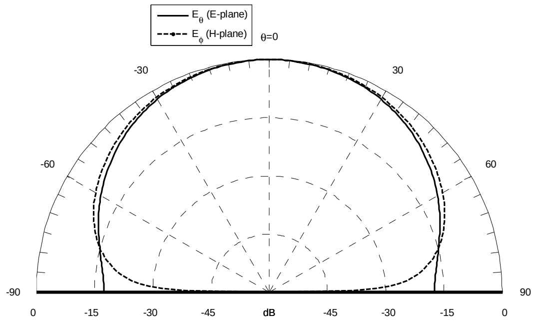


(a)



(b)

Figure 5. (a) Resonant frequency. (b) Quality factor of circular microstrip antenna versus anisotrpy ratio when $\varepsilon_x = 2.43$ and ε_z varies.

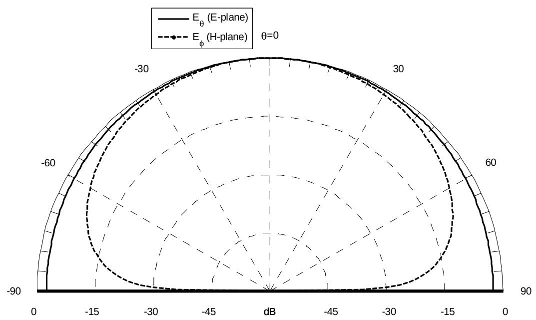


(b)

Figure 6. Radiation patterns of the fundamental resonant mode of a circular disk microstrip antenna on uniaxial substrate for two different values of anisotropy ratio.(a) AR=0.5, h=0.49mm, a=9.9617mm (b) AR=2, h=0.49mm, a=9.9617mm.

In Fig. 5(b) the variation of antenna quality factor with respect to anisotropy ratio is shown. It is observed that in order to decrease the quality factor to achieve wider bandwidths, anisotropy ratio must be more than unity. Using an anisotropy ratio less than one leads to a high quality factor suitable for resonator design.

In “Fig. 6” we compares the radiation patterns obtained for a circular disk microstrip antenna on uniaxial substrates with two different values of anisotropy ratio of 0.25 and 2. It is observed that the directivity of the antenna with greater value of anisotropy ratio is more than the smaller one. This treatment has physical agreement with the results obtained in Fig. 4(a). We saw in Fig. 4(a) that the greater anisotropy ratio the greater resonant frequency and of course the smaller operating wavelength. Concerning that the patch size is frozen, the ratio of patch size to wavelength will be greater and accordingly we get greater directivity.



(a)

V. CONCLUSION

The neural model presented in this work has been found to possess high accuracy and require no complicated mathematical functions. Using these models one can calculate resonant frequency of circular microstrip antenna on isotropic or uniaxially anisotropic substrate accurately. If more data set is used for the training, the ANN model gives more robust results. The ANN models, give better results, this results prove that there is considerable resonant frequency shift, quality factor value change and radiation pattern variation due to anisotropy of substrate. So, it can be concluded that both the models are efficient for the prediction of resonant frequency of the circular patch and radiation pattern for all the practical purposes. An ANN model is found to be well-suited for the development of fast and accurate CAD algorithms due to the improved accuracy achieved within small computational time. The full analysis can be extended for other patch shapes and their arrays in order to determine the air gap tuning effect on the operational characteristics.

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