Modeling of Microstrip Patch Antenna Using Artificial Neural Network Algorithms

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Abstract. In this paper, a novel method of approach of designing the microstrip antenna operating at Industrial, Scientific and Medical band is being analyzed and simulated. As the resonant frequency of the antennas configuration is dependent on the geometrical confinement and dimensions of the antenna the analysis and synthesis of the resonant frequency is carried out using the Artificial Neural Network (ANN) model. The physical dimensions like width (W), Length (L), Height (h), Dielectric permittivity are taken into consideration for the ANN algorithms Radix Basic Function Model (RBF) and Multilayer Perception Algorithm (MLP). The feed forward method and reverse side method is used for the analysis and synthesis of the parameters in determining the resonant frequency (f_r) of the Antenna. The antenna configuration is designed by calculating using conventional formulas for the values of Length, Width and Height for the Operating frequency. A good matching is observed in terms of the values of the geometrical parameters between the RBF, MLP and Conventional formula method. The antenna configuration is analyzed using CST and the electrical parameters namely Return loss (S_{11}), Gain and directivity are determined. Further the same is fabricated. The test and measurement values are also produced and a good agreement is observed in terms of Returnloss (S_{11}). This study and analysis of the ANN Model of designing can be extended further in the design of the RF and Microwave components also. As a future scope this design of Antenna using Artificial Neural Network ANN can be extended to the design of Meta materials antennas for communication applications.

Keywords: CST · Returnloss · Multilayer Perception Algorithm · Radix Basic Function Model

1 Introduction

In this fast growing and ever changing era of science and technology various algorithms and techniques plays a vital role. The design of such systems has inspired various

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researchers and young aspirants to focus towards the development of wireless communication systems for the wireless systems. In recent days the cost effective and wide bandwidth antenna systems are developed which enhances the overall efficacy and performance of the entire wireless system. A number of methods are available to design antennas which operate for the particular resonant frequency. However the theoretical and experimental investigations are carried out for enhancing the electrical performance parameters and the operation of antenna systems. Various research aspirants focused towards the development of different antenna models. The challenging task is determining the parameters for the particular resonant frequency for a particular application. The frequency of operation or the resonant frequency will be more predominantly dependant on the various mechanical parameters of the antenna system. Enormous amount of work is carried out in determining the mechanical parameters of the antenna system through theoretical and mathematical investigations [1, 2]. However the necessity of extensive analysis for the calculation of the mechanical parameters which determines the frequency of operation is to be carried out using a scientific method or an algorithm. One such interdisciplinary stream of science and technology is Artificial Neural Networks (ANN) [3]. The concept and algorithms of the artificial neural network will help in solving the problem and finding the mechanical parameters of the antennas. This concept of implementation of ANN in the determining the frequency of operation through the mechanical parameters has brought a tremendous change in the ease of the design of the antennas for various frequencies [4]. In this paper the analysis of the problem has been defined to find out the resonant frequency for a given substrate material which have the dielectric coefficient and the geometric model.

2 Antenna Configuration

Antennas play a crucial role in the Wireless systems. The performance of the wireless systems depends on the antenna design and its performance [2, 5]. In recent days Microstrip patch antenna has gained the attention of the research community. Patch antenna configuration consists of a radiating structure mounted on the dielectric substrate on one side and the metallic ground on the other side [8]. The substrate layers are generally isotropic in nature where as the height (h) dielectric permittivity (ε_r), length and width are the mechanical parameters which influence the performance of the antenna system. Anti isotropic substrates can also be considered for the design of microstrip patch antenna. The improvised efficiency and bandwidth is generally obtained by using the substrates of less dielectric permittivity values whereas generally the value of the dielectric permittivity ranges from 2.2 to 12. The below Fig. 1 depict the model of the basic patch antenna configuration.

The modeling of the antenna is carried out by calculating the value of the effective dielectric permittivity of the substrate as stated in Eq. 1, length and width of the radiator as specified in Eq. 2

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{1}$$

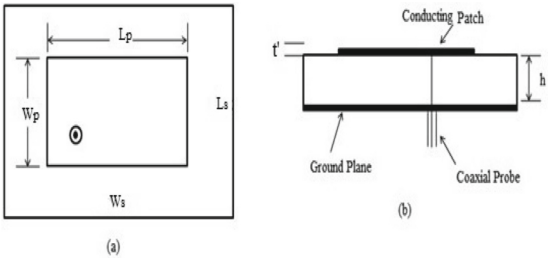

Fig. 1. Antenna structure [1, 2]

$$W = \frac{1}{2f_r\sqrt{\varepsilon_r\mu 0}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\varepsilon_0\mu 0}} - 2\Delta L \tag{3}$$

3 ANN Model of a Patch Antenna

In recent times various ANN techniques are developed for the calculation and determination of the resonant frequency of various shapes of patch of the antennas. The evaluation of the frequency of operation of a patch antenna is a prime factor for determining the behavior. The test data sheets used for these models are to be obtained analytically of from the earlier literature work carried out by various research aspirants. The ANN models are also utilized for determining the impedance of the patch antenna. The utilization of the neuro fuzzy networks is one of the fastest techniques of determining the frequency of operation of the patch antenna. The calculations or the analysis is based on the wave number of the domain which results in the spectral analysis to analyze the behavior of the model.

The ANN model is developed to calculate the dimensions of the patch of a microstrip patch antenna. The variables of the patch width (W) and length (L) are considered as a function of the input variables, where as height of the dielectric substrate is (h) and dielectric permittivity ($\mathcal{E}_r$) of the material is considered in terms of x and y directions namely ($\mathcal{E}_x$, $\mathcal{E}_y$) which determines the electrical properties of the substrate material respectively. Figure 2 shows the ANN model of the antenna which provide the details of the input parameters and output parameters of the black box.

The ANN Model usage in determining the parameters of antenna can be done in two different methods. One is through forward method in which the input parameters are used to synthesize to find the output. The synthesis model of the ANN model is as shown in Fig. 2.

The second one is by reverse method in which the output parameter is obtained from the chosen inputs which are at the input side. This method is called as analysis model of the ANN model. To determine the output parameters of th ANN algorithm by these two methods the ANN algorithms are need to be studied which are as described in the next section of this paper.

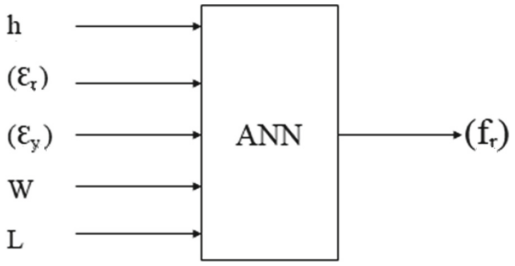

Fig. 2. Input and output parameters analysis using ANN model

4 ANN Algorithms

The artificial neural network model is developed based on the input and out variables for the microstrip patch antenna configuration. In order to determine the parameters on an antenna suing the ANN techniques various algorithms are to studied. One of these algorithms like Radial Basis Fucntion (RBF) and Multilayer Perceptions (MLP) are used for the ANN Model [13]. The brief of these RBF and MLP is a state below.

4.1 RBF Model

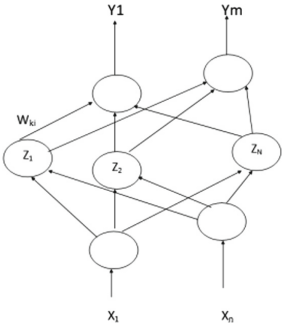

Fig. 3. Radial Basis Function Network of ANN Model

In this model of ANN the feed forward networks are used for a hidden layer which uses the radial function for activating the hidden neurons [14]. A typical structure of the model is shown in Fig. 2. Gaussian and multi-quadratic functions are generally used for activating the radial function in this RBF network (Fig. 3).

In the RBF model of ANN around 45 samples are tested and for five inputs and single output out of which number of inputs is 4 and number of outputs is 2 respectively in order to synthesize the ANN.

4.2 MLP Model

MLP models are trained by the backward propagation algorithm. These MLP networks are used to transform the data into a desired response which will be highly useful in

modeling the pattern classifications. In the MLP model which consists of a single unit of a neuron is composed of the weight which will be sum of the input and threshold value for activating the function. As the name itself specifies the multilayer perception which means the output of one neuron unit will act as an input for the next presiding layer.

The configuration of an MLP will be of four input neurons which consist of 10 and 5 neurons in the hidden layer. The rate of learning will be 0.1 with a goal estimation of 0.01 for approximately 450 echos. The accuracy level will be best in the range of the value of spread is 0.01 appropriately.

5 Determining the Parameters of Patch Antenna Using ANN

The training is performed by using the 45 data sets which comprises of the various mechanical parameters of the patch namely width, length, height, dielectric permittivity will act as input and the resonant frequency of operation will be the output of the ANN model. The ANN network is trained for a good network convergence condition [7]. The ANN model was tested for input frequencies the entire range. The Multilayer perception model consists of layers which are namely MLP1 and MLP2 and MLP3 which uses scaled conjugate, Resilient and Levenberg Marquardt algorithms for optimizing the values in the ANN model [9, 10]. The accuracy of the synthesis ANN model for the designed 4 networks is being synthesized and Analyzed as specified in the Table 1. The RBF is found to be the best approximation with the structure of the antenna. The synthesized results are shown in the Table 2 respectively (Tables 3 and 4).

Table 1. ANN synthesis and its comparison with the targets

Height (cm)	Permittivity	Frequency (GHz)	Width (cm)	Width – RBF (cm)	Length (cm.)	L RBF (cm.)
0.3250	2.33	2.320	5.6300000e+000	5.5945405e+000	3.9000000e+000	3.856472e+000
0.3250	2.33	2.980	4.4800000e+000	4.4451162e+000	3.0800000e+000	3.040534e+000
0.3250	2.33	4.210	2.9200000e+000	4.4174521e+000	1.9100000e+000	1.900053488e+000
0.3250	2.33	5.740	1.9500000e+000	1.9347063e+000	1.4000000e+000	1.295348658e+000
0.3250	2.33	6.750	1.6900000e+000	1.6523145e+000	1.1000000e+000	1.103542580e+000
0.3250	2.33	7.600	1.3900000e+000	1.3300561e+000	8.000000e−001	9.52145683e−001
0.3250	2.33	8.170	1.0500000e+000	1.0352471e+000	6.000000e−001	6.87589405e−001
0.3250	2.33	9.150	1.7000000e+000	1.7005635e+000	7.000000e−001	7.01865487e−001
0.9425	2.33	4.630	6.9800000e+000	6.9845726e+000	1.2000000e+000	1.25798458e+000
0.4100	2.55	7.134	8.9700000e+000	8.9502548e+000	1.3550000e+000	1.35874587e+000
0.4500	2.55	6.090	1.0000000e+000	1.0325489e+000	1.3500000e+000	1.35645821e+000
0.4670	2.55	5.820	8.1300000e+000	8.1765896e+000	1.4200000e+000	1.4105879e+000
0.4870	2.55	6.280	7.8000000e+000	7.8356789e+000	1.3400000e+000	1.3414655e+000
0.5300	2.55	5.970	7.9200000e+000	7.8236548e+000	1.5200000e+000	1.5187655e+000
0.1670	2.33	5.030	1.7300000e+000	1.7156487e+000	1.7600000e+000	1.7643571e+000

Table 2. Accuracy of the ANN synthesis neural networks

ANN model	Accuracy
RBF	99.56
MLP1	97.65
MLP2	94.50
MLP3	93.88

Table 3. ANN analysis and its comparison with the appropriate targets

Height (cm)	Permittivity	Width (cm)	Length (cm)	Frequency-target (GHz)	Frequency-RBF (GHz)
0.3250	2.33	5.63	3.90	2.3200000e+000	2.1008457e+000
0.3250	2.33	4.48	3.08	2.9800000e+000	2.9602547e+000
0.3250	2.33	2.92	1.91	4.2100000e+000	4.2060254e+000
0.3250	2.33	1.95	1.40	5.7400000e+000	5.7584687e+000
0.3250	2.33	1.69	1.10	6.7500000e+000	6.6985657e+000
0.3250	2.33	1.39	8.00	7.6000000e+000	7.7985467e+000
0.3250	2.33	1.05	6.00	8.1700000e+000	8.1264785e+000
0.3250	2.33	1.70	7.00	9.1500000e+000	9.0854678e+000
0.9425	2.33	6.98	1.20	4.6300000e+000	4.5687521e+000
0.4100	2.55	8.97	1.35	7.1340000e+000	7.0638452e+000
0.4500	2.55	1.00	1.35	6.0900000e+000	6.1058765e+000
0.4670	2.55	8.13	1.42	5.8200000e+000	5.8545702e+000
0.4870	2.55	7.80	1.34	6.2800000e+000	6.4265790e+000
0.5300	2.55	7.92	1.52	5.9700000e+000	5.9845875e+000
0.1670	2.33	1.73	1.76	5.030	5.0158689e+000

Table 4. Accuracy of the ANN analysis of the neural networks

ANN model	Accuracy (%)
RBF	99.56
MLP1	97.65
MLP2	94.50
MLP3	93.88

6 Modeling the Patch Antenna in CST

The design of patch antenna is carried out in computer simulation tool and the dimensions are calculated for the antenna designed for the specific frequency of operation. The results obtained in the design are as shown in the Fig. 4 (Figs. 5, 6, 7, 8 and 9).

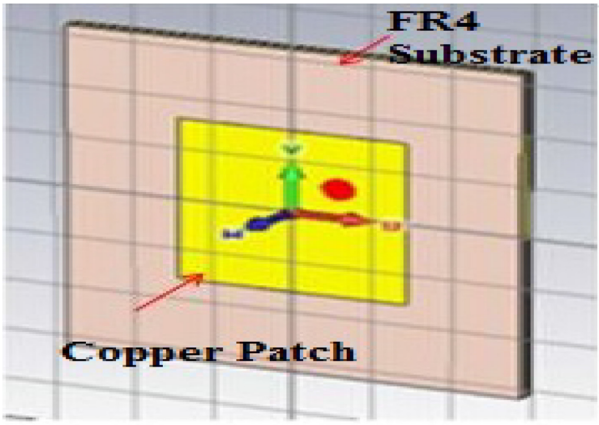

Fig. 4. Conventional MSTPA designed in CST

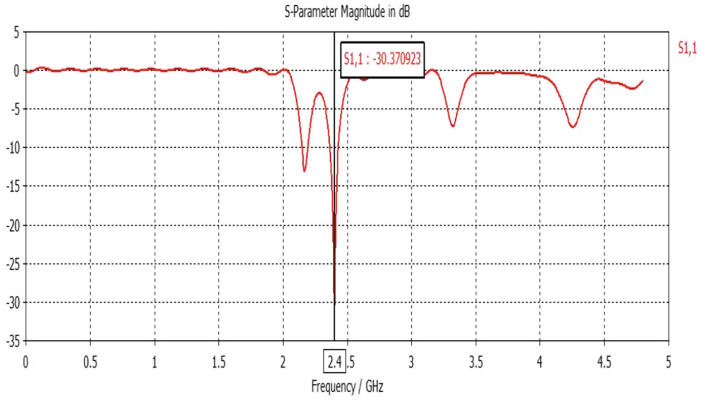

Fig. 5. S_{11} of the conventional MSTPA designed in CST

The Tables 5 and 6 show the comparative analysis of the performance parameters of the microstrip patch antenna. The geometrical parameters are also compared which are determined by using the ANN algorithms and the calculated by using the formulas using conventional method as specified in table. A good matching is found between the geometrical values of the antenna structure determined by using the ANN model and conventional method.

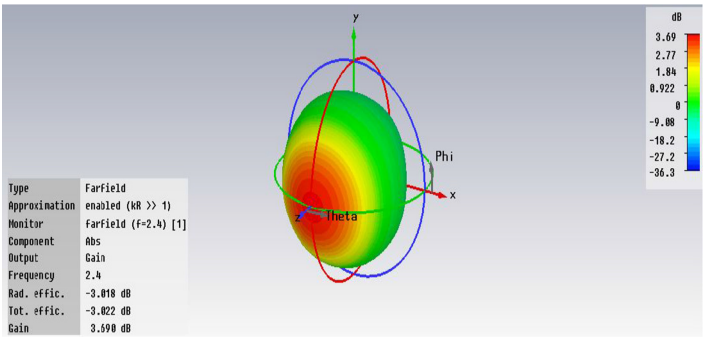

Fig. 6. Gain of the conventional MSTPA designed in CST

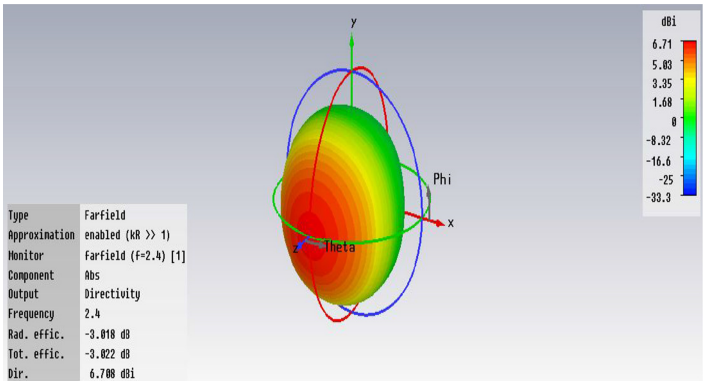

Fig. 7. Directivity of the conventional MSTPA designed in CST

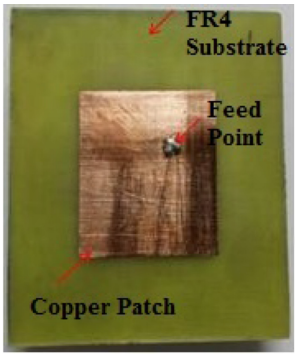

Fig. 8. Fabricated conventional MSTPA

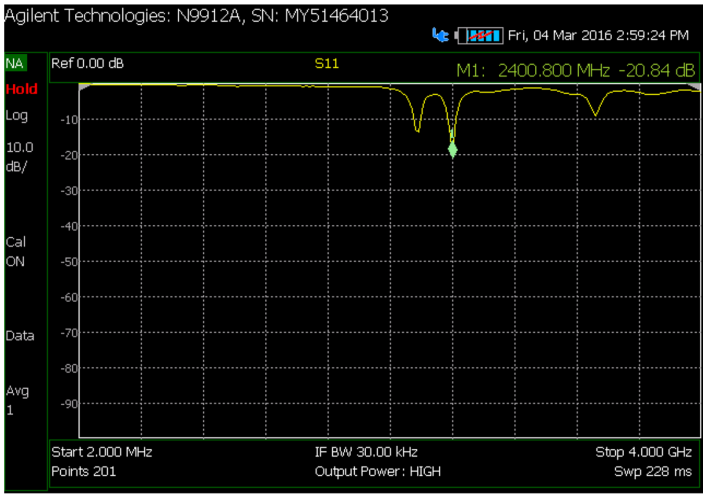

Fig. 9. S11 of the fabricated conventional MSTPA

Table 5. Comparative analysis of geometrical parameters for the Patch Antenna using ANN, conventional formula method simulated in CST and fabricated structure.

Parameter	ANN-RBF	ANN-MLP	Simulated in CST	Fabricated structure in CST
Length	5.63	5.63	5.43	5.43
Width	4.63	6.98	5.23	5.23
Frequency (GHz)	2.33	2.33	2.4	2.4

Table 6. Comparative analysis of electrical performance parameters for the Patch Antenna designed in CST and fabricated structure

Parameter	Simulated in CST	Fabricated structure in CST
Frequency (GHz)	2.4	2.4
Return Loss (S_{11}) (dB)	−30.37	−20.84
Gain (dB)	3.698	–
Directivity (dBi)	6.780	–

7 Conclusion

In this paper, an approach presented for designing of MSTPA (Microstrip patch antenna) using artificial neural network. The synthesis is carried out using the forward scale and analysis by carefully considering reverse side of the problem. The dimensions can be obtained with high accuracy in terms of length, width of the patch which acts as input

to the preliminary input layer of the ANN model and the frequency of resonance will act as the output of the ANN model antenna using the Artificial neural network as a tool. A good matching is found between the geometrical values of the antenna structure determined by using the ANN model and conventional method. Almost 98% Accuracy is obtained in determining the geometrical dimensions. The same is fabricated and the acceptable matching is obtained in the electrical performance of the S11 value of the simulated and fabricated structure of the antenna. Further the modeling of the antenna using ANN can be extended for designing the patch antenna of any shape of the patch for the frequency of interest. The ANN modeling can also be used for design of RF devices, multilayered patch antenna, Metamaterials also.

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