Analysis and Parameter Estimation of Microstrip Circular Patch Antennas Using Artificial Neural Networks

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Abstract Microstrip circular patch antenna play a vital role in the mobile communication area. In round shape patch antenna, radius of round patch is important for generating the required resonant frequency. So proper functioning and high accuracy is required for design specifications of microstrip antenna. This paper discusses the design of round shape microstrip patch antenna using ANN. The mathematically calculated results using ANN model are compared with the Computer Simulation Technology (CST) to verify the results. The calculated resonant frequency is retained at S-band (2–4 GHz). S-band is used for RF power and high data rate application.

Keywords Microstrip patch antenna · Artificial neural Network (ANN)
Resonant frequency · Back propagation algorithm

1 Introduction

Microstrip patch antennas are utilized in large number of areas like mobile antenna system, satellite communication, aircraft system, and biomedical system. It has some effective properties like more economical, light weight, simple in fabrication, and more reliable [1]. Nowadays, these attractive aspects make microstrip antenna more in demand. Many configurations such as rectangular, elliptical, circular, ring, and square are used as patch in microstrip antenna. Circular patch is study in this paper because it is quite simple to fabricate [2]. The resonant frequency is essential to determine because overall antenna performance confides on it. Resonant frequency

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also depends on the radius of the round patch which is calculated by formula [3]. This range of resonant frequency is used for radio astronomy, microwave devices and communication, wirelesses LAN, modern radars, etc. So fast, efficient method is required to compute the design parameter of antenna. ANN has inherent property to estimate the result with missing data or inappropriate data. Many prediction-based solutions are obtained using ANN [4]. It is also time reducing and fast method to handle the big data bank [5]. In this paper, proposed ANN model is generating the resonant frequency using different radius for circular patch antenna with dielectric constant of material is used for antenna. For learning of ANN model, back propagation algorithm is used. In this algorithm, inputs are trained to the corresponding target outputs. Calculated result of ANN model is compared with the CST Software.

The rest paper is arranged as follows. Section 2 defines the antenna design analysis, Sect. 3 discusses the synthesis of design of circular microstrip antenna by using NN (neural network), Sect. 4 shows the results and Sect. 5 defines the conclusion.

2 Antenna Design Analysis

Circular patch antenna operates at 3.96 GHz. A FR-4 substrate is used to print the circular patch antenna. The dielectric constant of FR-4 is 4.7 [6]. A circular patch antenna has been printed on dielectric substrate. A large ground plane is formed on the bottom side of the substrate. There are two main feeding techniques to evaluate the circular patch antenna via microstrip method and coaxial feed method [7]. The circular patch has been impressed on the dielectric substrate. The dominant mode is TM_{110} of microstrip circular antenna.

$$(f_r)_{mno} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\left(\frac{X'_{mn}}{a}\right) \quad (1)$$

To calculate the f_r (resonant frequency) Eq. (1) is used.

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h} + 1.7726\right)\right]\right\} \wedge 1/2} \quad (2)$$

where

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \quad (3)$$

$$(f_r) = \frac{1.8412 v_0}{2\pi a\sqrt{\varepsilon_r}} \quad (4)$$

ε_r Dielectric constant of the substrate
h Height of the substrate in mm

a Radius of the patch
υ_o Speed of light

The structure of the circular patch antenna is printed on a FR-4 substrate with thickness of h = 1.5 mm and relative dielectric constant ε_r = 4.7 as shown in Fig. 1 side view of circular patch antenna. The dimension of the dielectric substrate is taken 50 × 42 mm, where width (W_s) and length (L_s) of the substrate show in Fig. 2 as front view of microstrip round shape antenna. The radius of the microstrip round shape antenna has been calculated 10 mm at desired resonating frequency 3.8 GHz using Eq. (1) and thickness of the patch was considered 0.01 mm. The patch antenna has been printed on one side of a dielectric substrate and a metallic ground plane of size 50 × 42 mm is formed on the other side of the substrate.

The antenna structure is fed by a coaxial feed of characteristic impedance of 50 Ω through ground plane. Front view of the microstrip circular antenna is shown

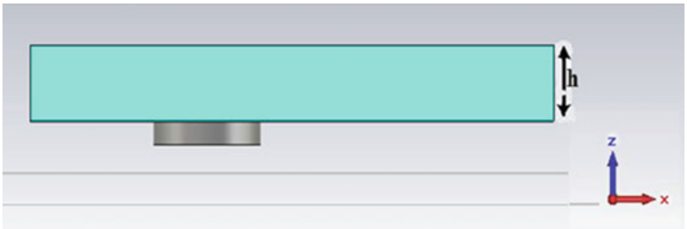

Fig. 1 Side view of microstrip circular antenna

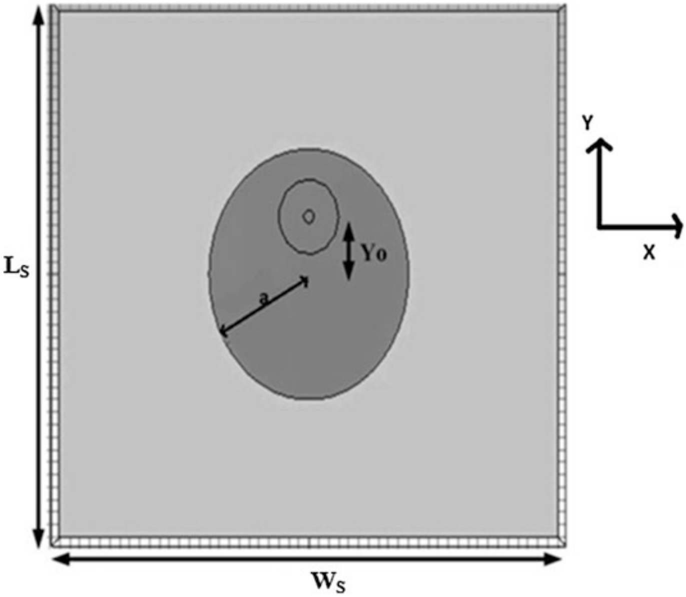

Fig. 2 Front view of microstrip circular antenna

in Fig. 3. To design a coaxial probe, the dielectric constant is fixed 4.7, the inner (D_{in}) and outer diameter (D_{out}) of coaxial probe is chosen 1 and 6 mm respectively. The feed location for the patch antenna is found to be of the distance (y_0 = 2.7 mm) away from the center of the patch along the y-axis, where the appropriate impedance matching of 50 Ω has been achieved. Table 1 shows the parameter of proposed microstrip circular antenna.

Figure 3 shows the S_{11} magnitude in dB plot of the circular patch antenna using coaxial feed method at 3.8 GHz. Because in coaxial feeding method it can be easily to set the impedance matching by adjusting the feed position [8]. It has been observed that the circular patch antenna radiates at single resonating frequency. Figure 3 shows the S parameter graph with return loss value is −12.49 dB at gain of 5.6 dB for circular patch antenna.

The E-plane radiation pattern is directional since the rotating electric current enters the radio wire through the feed line circular domain intersection and leaves the receiving wire through the transmitting edge of the circular plot [8]. They frame an electric field design having field maxima at the transmitting edges toward radiation and field minima at the focal point of the patch. So an arch molded radiation example is framed which has appeared in Fig 4.

The magnetic field that is prompted because the electric field is opposite to the electric field lines in H-plane [8]. It encompasses the whole electric field lines and producing a complete circular modeled radiation design. In this way, the radiation example of the H-Plane is round fit as a fiddle (i.e., Omnidirectional in nature) which is appeared in Fig. 5. It is observed in Figs. 4 and 5 that the gain is to be 5.6

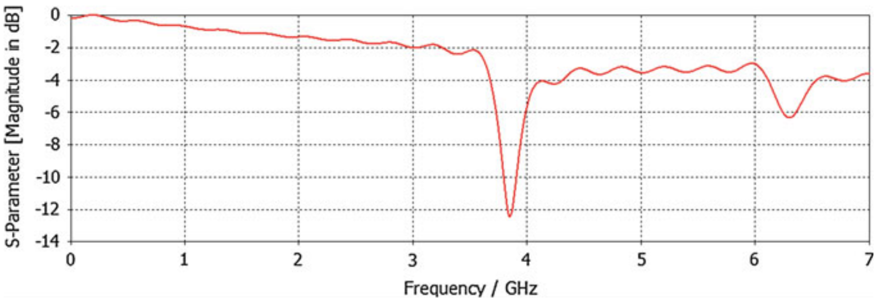

Fig. 3 S parameter versus frequency

Table 1 Circular patch Antenna design parameter

Parameters	Dimension (mm)
Radius of the round patch (a)	10
Thickness of the substrate (h)	1.5
Outer diameter of coaxial feed (D_{out})	6
Inner diameter of coaxial feed (D_{in})	1
Feed location from the center of the patch (y_0)	2.7

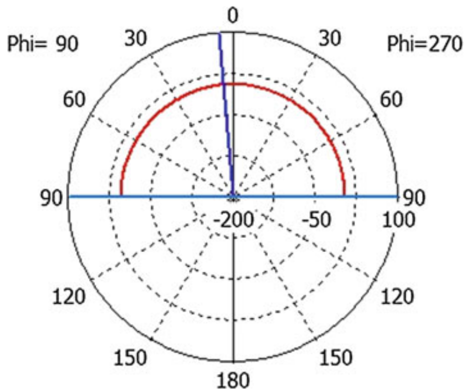

Fig. 4 E-plane radiation pattern of circular patch antenna

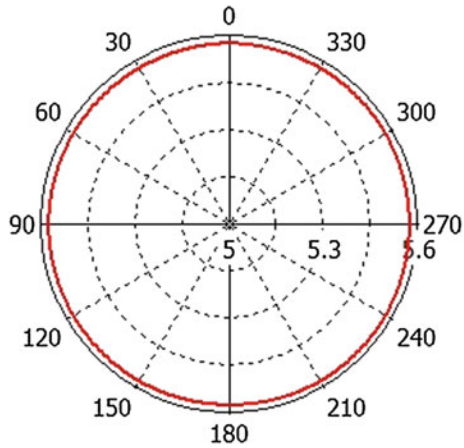

Fig. 5 H-plane radiation pattern of circular patch antenna

Table 2 Performance parameters of round shape patch antenna

Frequency (GHz)	Return loss magnitude (dB)	BandWidth (MHz) at −10 dB reference level	Gain (dBi)
3.82	−12.49	105	5.6

dBi at 3.8 GHz. Table 2 shows the performance parameter of circular patch antenna on the basis of H and E plane radiation pattern.

3 Design of Microstrip Round Shaped Antenna Using ANN (Artificial Neural Network)

In proposed neural network model, three-layer architecture is used where one hidden layer is between input and output layer. ANN architecture for microstrip circular antenna is shown in Fig. 6. As input radius and dielectric constant is the parameter to input layer. For training to the model, 400 data are used. In 400 data, 260 data are used for training, 60 data are used for testing, and rest 60 data used for validation. Equation (1) is used for generating the input parameter. The output parameter is the resonant frequency. Sigmoid activation function is used in hidden layer. The algorithm is used for learning to network is Levenberg–Marquardt algorithm which has rapid convergence.

These training algorithms of neural network are utilized to train the samples which have only aim to minimize the error to acquire the resonant frequency at defined dimensions [4]. By varying the number of neurons in hidden layer, ANN model is trained. Best model is selected on the basis of minimum mean square that is achieved at given number of neuron to the hidden layer [9].

4 Result and Discussion

In this study, we used nftool fitting tool of MATLAB to determine the best possible test results. In fitting nftool, we declare the input layer, hidden layer, and the activation function to be used to get a desired output. By changing the number of neuron in hidden layer, we trained the network. Best performance ANN model is selected on the basis of minimum mean square error. Table 3 shows the comparison

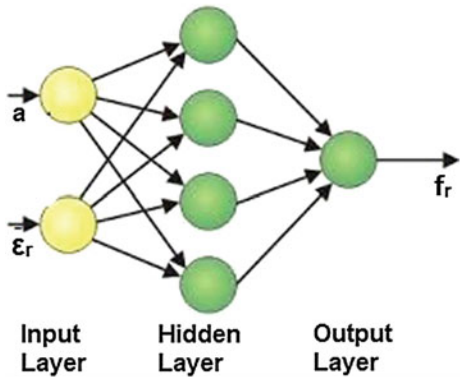

Fig. 6 Architecture of ANN for circular patch antenna

Table 3 Shows the MSE versus number of iterations with varying the number of neuron in hidden layer

S. No.	No. of hidden neurons	Mean square error	No. of iterations
01	5	5.7426e−10	85
02	10	2.9786e−11	259
03	15	1.7594e−12	568
04	20	1.9127e−08	56

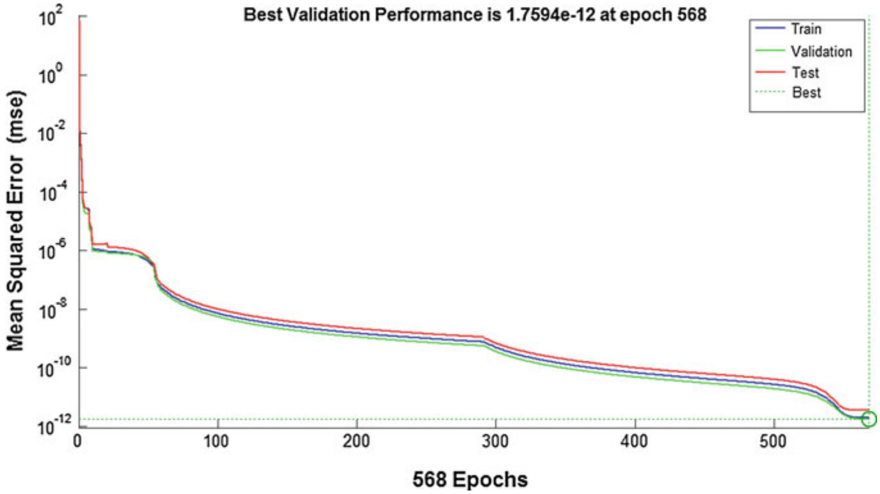

Fig. 7 Graph of performance of training, validation, and test data sets with respect to epochs for circular patch antenna parameter

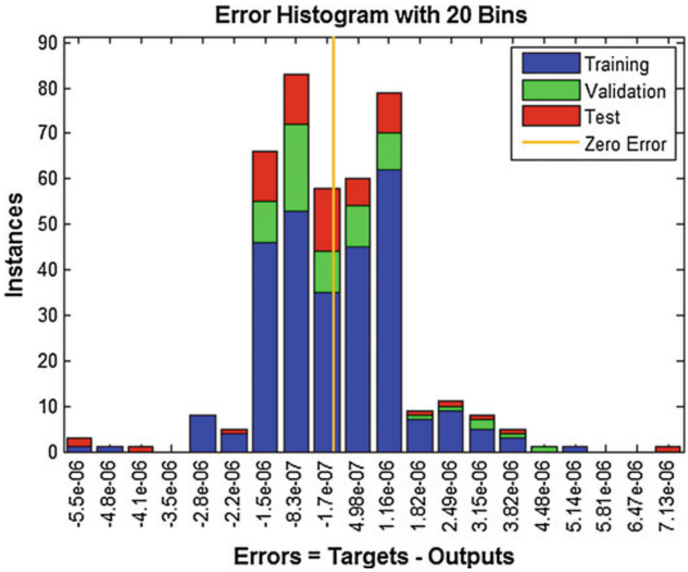

Fig. 8 Error histogram for ANN training

of mean square error with respect to number of iteration while changing the number of neuron in hidden layer.

Figure 7 shows the performance of training, validation, and test data sets with respect to epochs for circular patch antenna. It is seen that the best training performance was meet at epoch 568 and the mean square error is 1.7594×10^{-12}. Figure 8 shows the error histogram of proposed neural network model for circular patch antenna.

5 Conclusion

The target of this paper is to calculate accurately the resonant frequency of the circular microstrip patch antenna with the help of artificial neural network model. This neural network model possesses the high accuracy during the analysis. By varying the number of neuron in hidden minimum mean square error is achieved. Mostly, antenna design process is time consuming but with neural network model it reduced the process time and increased the accuracy to synthesis process of antenna parameter design.

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