

Design and Analysis of Microstrip Line Feed Topped T Shaped Microstrip Patch Antenna using Radial Basis Function Neural Network

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Abstract – This paper deals with the design of a microstrip line feed topped T shaped microstrip patch antenna that gives dualband characteristics at 4 GHz and 6.73 GHz respectively. The simulation of proposed antenna geometry has been performed using method of moment based IE3D simulation software. A radial basis function neural network (RBFNN) is used for the estimation of bandwidth for dualband at 4 GHz and 6.73 GHz respectively. In RBFNN model, antenna parameters such as dielectric constant, height of substrate, and width are used as input and bandwidth of first and second band is considered as output of the network. To validate the RBFNN output, an antenna has been physically fabricated on glass epoxy substrate. The fabricated antenna can be utilized in *S* and *C* bands applications. RBFNN results are found in close agreement with simulated and experimental results.

Keywords: Artificial neural network, Microstrip patch antenna, Radial basis function, Bandwidth.

1. Introduction

Microstrip patch antennas (MSAs) have gained attention of researchers due to the topical development in the field of wireless communication. These antennas are in mammoth demand due to their wide range of applications such as mobile, satellite, terrestrial cellular, personal communication systems [1-3] etc. Microstrip antennas plays vital role in efficient reception and transmitting of signals in wireless communications. These antennas become more abundant when single antenna can be used for both transmission and reception of the signals, i.e., for dualband operation has two or more than two bands of frequencies. This provoked the researchers to design microstrip patch antenna for dualband operation.

Dualband MSA was first reported by Wang and Lo [4] in 1984. Subsequently, plethora of dualband microstrip antennas have been reported [5-20]. In dualband microstrip antenna design, determination of bandwidth is a fundamental point because the bandwidth is important parameter of microstrip patch antenna [21-27]. Two types of analysis are mostly reported in the literature [21-27] for calculating the bandwidth of these antennas. These analysis techniques are numerical and analytical methods. Both these methods have its own limitations. Analytical methods are applicable for few specific shapes of the patch geometry whereas a numerical method is applicable for all shapes of the patch geometry and requires much time for

solving the differential equations. Another drawback is that for any minor change in geometry it requires new solution for geometry and thus it becomes time consuming method. To avoid all these difficulties, a novel method is suggested in this paper, which is the application of artificial neural network (ANN) model.

ANNs are suitable models for parameter optimization of microstrip patch antenna. ANN models are computationally much more efficient than EM models (analytical and numerical methods). The ANN provides fast and accurate models for MSA modeling, simulation, and optimization. ANN is computational tools and based on learning strategies. The application of ANN on the field of microstrip patch antenna is very recent. A number of papers [28-44] are present in the literature that signifies the importance of ANN in the field of microstrip patch antenna.

This work aims to design a microstrip line feed topped T shaped MSA for dual frequency operation using radial basis function neural network. In this work RBFNN is used for the optimizing the bandwidth of proposed antenna with respect to used dielectric material. The proposed antenna is physically fabricated for the verification of RBFNN results. The beauty of the proposed work is the combination of simulated, experimental, and ANN results. This paper is organized as follows, section 1 deals with the introduction, and section 2 deals with antenna geometry. Section 3 demonstrates the neural modeling and generation of data. Finally section 4 and 5 hold the results and conclusion of entire study respectively.

2. Antenna Design and Data Generation

In Fig. 1(a), the proposed antenna geometry is shown. A

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Received: May 20, 2014; Accepted: October 20, 2014

very low loss dielectric substrate glass epoxy with 1.58 mm height, $\tan\delta = 0.002$, and dielectric constant of $\epsilon_r = 4.7$ is used as the substrate for proposed antenna. The patch and ground plane are printed on the top and bottom of the dielectric substrate respectively. The dimension of the ground plane is $L_g \times W_g$. The radiating patch is designed and its dimensions are selected so as to achieve dualband characteristics. All the respective values of designing parameters mentioned in Fig. 1(a) are given in Table 1. The proposed antenna geometry is simulated using IE3D software [45]. Fig. 1(b) shows the physically fabricated microstrip antenna with ground plane on glass epoxy substrate. Microstrip line feeding is used here for the excitation of antenna geometry.

Fig. 2(a) - (b) shows the current distribution of the proposed antenna at frequencies 4 GHz and 6.73 GHz

Table 1. Design specifications for proposed antenna geometry

Parameter	Value
L_g	40 mm
W_g	40 mm
L	40 mm
W	2 mm
L_1	20 mm
W_1	2 mm
L_2	10 mm
ϵ_r	4.7
h	1.58 mm
$\tan\delta$	0.002

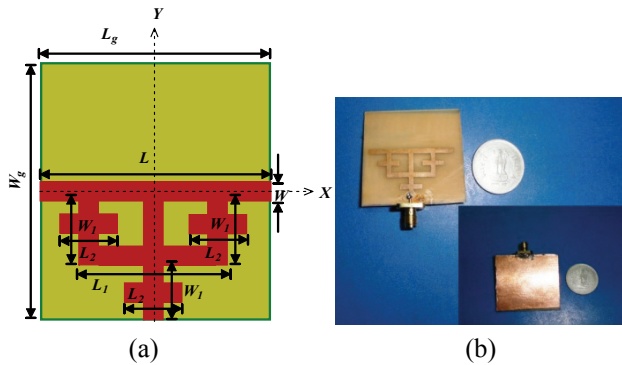


Fig. 1. (a) Proposed antenna design; (b) Fabricated antenna

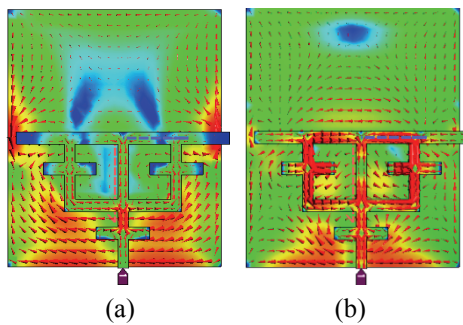


Fig. 2. Current distribution at frequency: (a) 4GHz; (b) 6.73GHz

respectively. From the Fig. 2(a), it is observed that a good amount of current with different length appears on the upper patch and ground plane of the proposed geometry. This different length of currents is responsible for generating dualband resonance frequencies. Fig. 2(b) depicted the current distribution at 6.73 GHz and found that, current flowing in two direction on the upper patch and ground plane due to which antenna characteristics improves in good radiation mode.

3. ANN Implementation

The implementation of ANN on above proposed geometry is mainly characterized in two steps; these are generation of data for training and testing, and selection of ANN topology.

3.1 Data generation

The bandwidth of microstrip patch antenna is mainly depending on the length (L), width (W), height (h), and dielectric constant (ϵ_r) of the substrate. Here, three parameters of the antenna are considered as an input for ANN model. In ANN model simulated, theoretical, and measured data can be used for training and testing. The simulated data of the proposed antenna geometry is obtained from method of moment based IE3D simulation software and used in RBF neural network model. Here 55 samples (34 training and 21 testing samples) are generated with the variation of dielectric constant from the range of $2 \leq \epsilon_r \leq 4.7$ and antenna geometry is simulated using IE3D software. Simulated reflection coefficient (S_{11}) of the proposed antenna geometry is recorded and their respective bandwidths for dualband are calculated. Whereas the other two parameters h and W are kept constant.

3.2 Model selection of artificial neural network

Artificial neural network uses several topologies. The most used topology of ANN are RBF and multilayer perceptron (MLP) neural network because the process of learning in this model (topology) has two stages and both of the stages are made more efficient by using appropriate learning algorithm. So, this is the leading reason of using RBFNN instead of MLPNN in the present work. A three layered radial basis neural network is selected for the estimation of bandwidth of proposed antenna geometry. Fig. 3 shows the structure of RBFNN model which have three layers. First one is the input layer consist of three source nodes with ϵ_r, h, w as an input function. Another is the output layer which consisting of two computational units with parameters bandwidth of first and second band respectively. Middle one is the hidden layer, which consists of $N = 60$ numbers of computation units as the size of the training samples and each unit of hidden layer is

mathematically described by radial basis function [46].

$$\varphi_j(x) = \varphi(\|x - x_j\|), j = 1, 2, \dots, N \quad (1)$$

where j_{th} input data point x_j defines the center of radial basis function and x is the dimension of input vector ($x = 3$). Gaussian function is implemented in each hidden layer of the network as shown in Fig. 3 and defined by

$$\varphi_j(x) = \varphi(x - x_j) \quad (2)$$

$$\varphi_j(x) = \exp\left(-\frac{1}{2\sigma_j^2}\|x - x_j\|^2\right), j=1, 2, \dots, N \quad (3)$$

where σ_j is measure of the width of j_{th} Gaussian function with center x_j . In this model, all the Gaussian hidden units are assigned a common width (σ). Fig. 4 shows the number of epochs to achieve minimum mean square errors (MSE) in case of RBF neural network. From the results of Fig. 4, it is observed that the level of mean square error is found

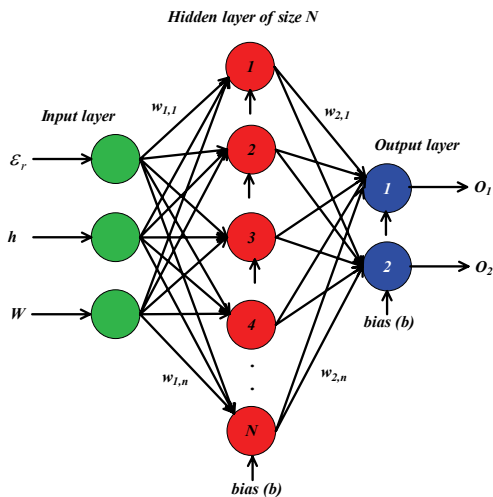


Fig. 3. Radial basis function neural network model

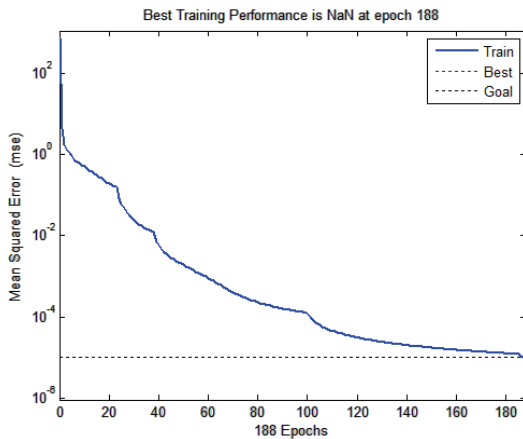


Fig. 4. Number of epochs to achieve minimum mean square errors

minimum with 188 numbers of epochs during the training of RBF neural network model.

4. Results and Discussion

Radial basis function neural network is tested with 21 sets of training data. Figs. 5-6 show the ANN output for estimated bandwidth with respect to several dielectric constant of the material for first and second band. The values of obtained bandwidth with respect to the dielectric constant have been evaluated at me (numbers of neurons in hidden layer) = 25, where all the other parameters, such as eg (error goal) = 0.0001, sc (spread constant) = 0.01 are kept constant for both of the cases. From these Figs. it is observed that at 25 neurons are in the hidden layer, error is minimized and RBFNN outputs are found in good agreement with the target bandwidth (%).

To validate the ANN results a tested sample of data is used for fabricating the antenna design as shown in Fig. 1(b). The reflection coefficient and radiation pattern of the fabricated antenna are measured using Agilent N5230 network analyzer and in anechoic chamber respectively.

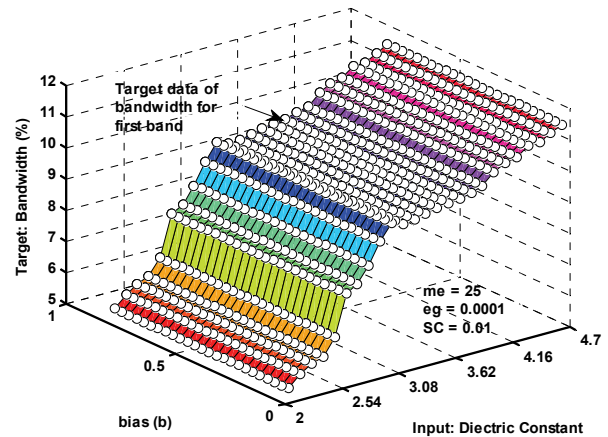


Fig. 5. Bandwidth of first band at 25 neurons

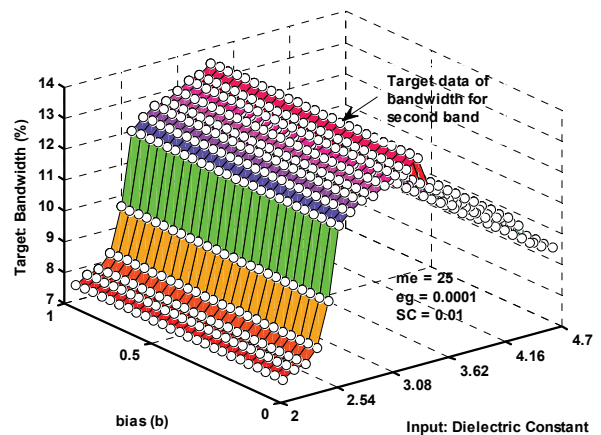


Fig. 6. Bandwidth of second band at 25 neurons

4.1 Proposed antenna results

Fig. 7 shows the variation in reflection coefficients with frequency for several heights of the used substrate glass epoxy. Fig. 7 demonstrates that the reflection coefficients for upper and lower resonance frequencies are shifted towards higher resonance side with decreasing the height from 1.58 mm to 0.25 mm. This change occurs as the substrate height is inversely proportional to the resonant frequency of patch antenna. Characteristics of proposed antenna are summarized in Table 2 with respect to the variation of different heights.

Fig. 8 shows the variation in reflection coefficient with

Table 2. Antenna characteristics with the variation of substrate height (h)

Substrate height (h)	Frequency (GHz)	S_{11} (BW%)	Remark
$h = 1.58$ mm	4 GHz, 6.58 GHz	10.42%, 9.42%	Dual band
$h = 0.75$ mm	4.26 GHz, 7.06 GHz	8.45%, 13.72%	Dual band
$h = 0.50$ mm	4.32 GHz, 7.37 GHz	7.87%, 14.6 %	Dual band
$h = 0.25$ mm	7.67 GHz	4.21%	Single band

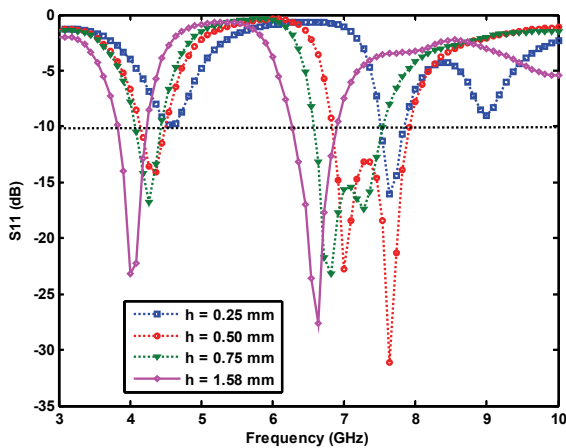


Fig. 7. Reflection coefficient variation for several heights of the substrate

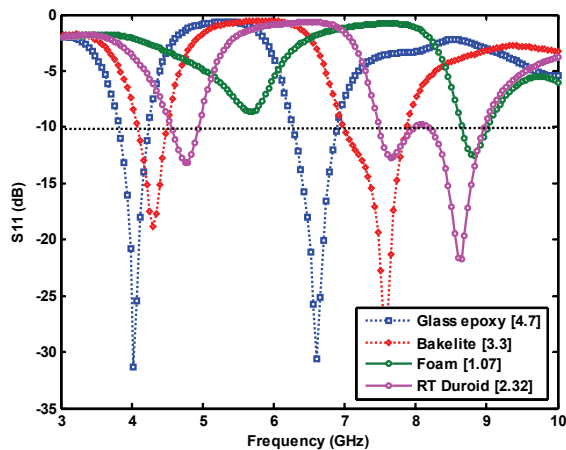


Fig. 8. Reflection coefficient variation for several dielectric materials

frequency for several dielectric materials. It is observed that the lower resonance frequency is shifted towards higher resonance side with decreasing the value of dielectric constant from glass epoxy to foam whereas higher resonance frequency is shifted towards higher resonance side. From the Fig. 8, it is clear that the obtained bandwidth is wider for Bakelite ($\epsilon_r = 3.3$) and RT Duroid ($\epsilon_r = 2.32$) substrate than the comparison of glass epoxy substrate. In this work, substrate used is glass epoxy and the reason behind selecting this substrate because it is easily available and less costly than the other substrates. Table 3 shows the summarized data of proposed antenna characteristics with the variation in dielectric constant (ϵ_r) of substrate. This data is used for the testing of RBF neural network model and star sign in Table 3 shows that glass epoxy ($\epsilon_r = 4.7$) substrate is used to validate ANN results.

The reflection coefficient spectrum of proposed antenna is shown in Fig. 9. It is evident that the simulated and measured results of reflection coefficient are in good agreement. In measurement, the reflection coefficient for $S_{11} \leq -10$ dB covers dualband at 4 GHz and 6.73 GHz. A non-noticeable difference occurs between the measured and simulated values of reflection coefficient due to the oddity in fabrication and soldering joint losses which was not included during the simulation. The characteristics of proposed antenna with ground plane and without ground plane are measured and their responses are summarized in Table 4. Fig. 10 shows the plot of gain and efficiency of the proposed antenna.

Table 3. Antenna characteristics with the variation in dielectric constant (ϵ_r) of substrate

Dielectric constant (ϵ_r)	Frequency (GHz)	S_{11} (BW%)	Remark
Foam ($\epsilon_r=1.07$)	8.83 GHz	4.27 %	Single band
RT Duroid ($\epsilon_r=2.32$)	4.74 GHz, 8.22 GHz	7.58 %, 17.72 %	Dual band
Bakelite ($\epsilon_r=3.3$)	4.29 GHz, 7.42 GHz	9.49 %, 11.63 %	Dual band
Glass epoxy ($\epsilon_r=4.7$)*	4 GHz, 6.58 GHz	10.42 %, 9.42 %	Dual band

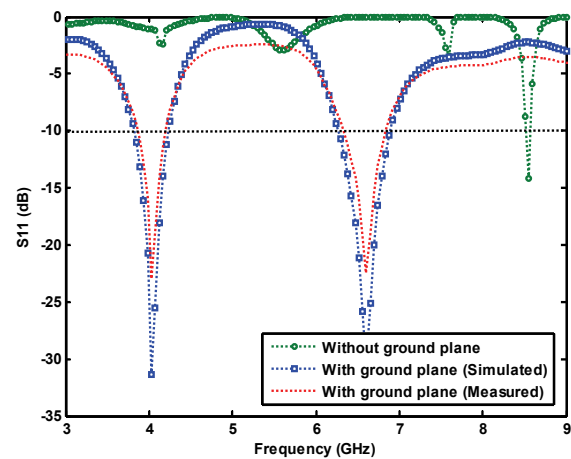


Fig. 9. Reflection coefficient with and without ground plane

Table 4. Antenna characteristics

Proposed antenna	Frequency (GHz)	S ₁₁ (BW %)	Remark
Without ground plane	8.5 GHz	4.20 %	Single band
With ground plane (simulated)	4 GHz, 6.73 GHz	10.42 %, 9.42 %	Dual band
With ground plane (measured)	4 GHz, 6.73 GHz	10.03 %, 9.12 %	Dual band

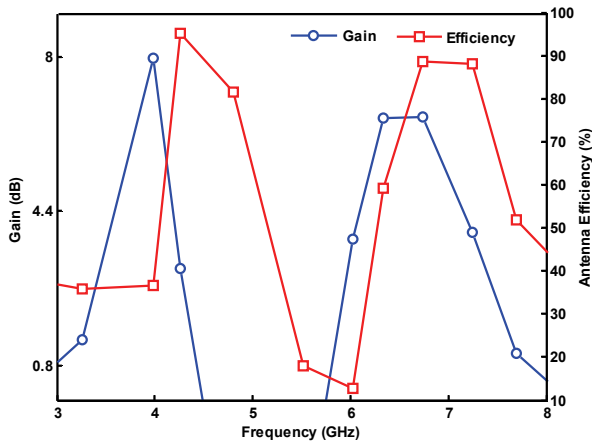


Fig. 10. Plot of gain and efficiency with frequency

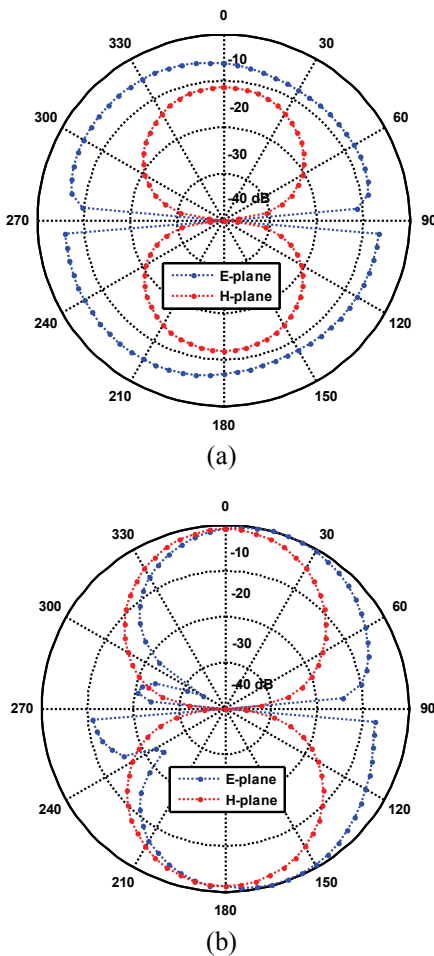


Fig. 11. Radiation pattern at (a) 4 GHz (b) 6.73 GHz

Table 5. Comparison of simulated, ANN, and measured results for bandwidth

Parameter	Bandwidth of first band	Bandwidth of second band
Simulated	10.42 %	9.42 %
ANN	10.4012 %	9.4145%
Measured	9.23 %,	9.12 %

The radiation patterns for *E-H* plane with resonant frequencies 4 GHz and 6.73 GHz are represented in Fig. 11 (a)-(b) respectively. The 3dB beamwidth is 56.3° for *E-theta*, $\phi=0^\circ$ and 67.4° for *E-theta*, $\phi=90^\circ$ at frequency 4 GHz. The 3 dB beamwidth is 44.6° for *E-theta*, $\phi=0^\circ$ and 70.1° for *E-theta*, $\phi=90^\circ$ at frequency 6.73 GHz. *E*-plane is measured in *xz*-axis and *H*-plane is measured in *xy*-axis. Comparison of simulated, ANN, and measured results are summarized in Table 5.

5. Conclusion

In this paper, microstrip line feed topped T shaped MSA is successfully analyzed using RBF neural network. The antenna operates in dual frequency bands at 4 GHz and 6.73 GHz respectively. The achievement of dualband with substrate glass epoxy is the focus of attention with etched topped T shaped as a radiator. An RBF algorithm has been successfully developed for the estimation of bandwidth for first and second bands respectively. RBF neural network model results are found quite satisfactory with high accuracy for bandwidth estimation. The reflection coefficient and radiation pattern results obtained are in closed agreement with simulated and experimental results.

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