Chapter 5

MICROSTRIP LINE FEED TOPPLED SHAPED PATCH ANTENNAS

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5.3 MICROSTRIP LINE FEED TOPPLED H-SHAPED PATCH ANTENNA

5.3.1 Simulated Antenna Design and Fabrication

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This chapter deals with the design of microstrip line feed Toppled T and H-shaped microstrip patch antennas that gives dual band (4 GHz, 6.73 GHz) and multiband (1.8 GHz, 3.5 GHz, 5.5 GHz) characteristics respectively. The simulation of proposed antenna geometries 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 dual band 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 study, antennas have been physically fabricated on glass epoxy substrate. The fabricated antennas can be utilized in S, C bands, PCS, WiMAX applications.
5.1 INTRODUCTION

Microstrip antennas play a vital role in efficient reception and transmitting of signals in wireless communications [1-3]. These antennas become more abundant when a single antenna can be used for both transmission and reception of the signals, i.e., for dual band operation has two or more than two bands of frequencies. This provoked the researchers to design microstrip patch antenna for dual and multiband operation.

Dual band MSA was first reported by Wang and Lo [4] in 1984. Subsequently, plethora of dualband microstrip antennas have been reported [5-20]. In dual band microstrip antenna design, determination of bandwidth is a fundamental point because the bandwidth is an 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 their 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 a time-consuming method. To avoid all these difficulties, a novel method is suggested in this chapter, which is the application of artificial neural network (ANN) model [28-44].

This chapter aims to design microstrip line feed Toppled shaped patch antennas for dual and multiband frequency operation. This chapter
comprises two antenna structures, Toppled T and H-shaped antenna. In which, RBFNN is used for the optimizing the bandwidth of Toppled T-shaped antenna. Further, Toppled H-shaped antenna is proposed, which is the extension of Toppled T-shaped antenna. The proposed antennas are physically fabricated for the verification of study. The beauty of this chapter is the combination of simulated, experimental, and ANN results. Detailed descriptions of both antennas are given in next sections.

5.2 MICROSTRIP LINE FEED TOPPLED T-SHAPED PATCH ANTENNA USING RBF NEURAL NETWORK

5.2.1 Antenna Design and Data Generation

The proposed antenna geometry is shown in Figure 5.1(a). A very low loss dielectric substrate glass epoxy with 1.58 mm height, \( \tan \delta = 0.002 \), and dielectric constant of \( \varepsilon_r = 4.7 \) 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 Figure 5.1(a) are given in Table 5.1. The proposed antenna geometry is simulated using IE3D software [45]. Figure 5.1(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.

Figure 5.2(a)-(b) shows the current distribution of the proposed antenna at frequencies 4 GHz and 6.73 GHz respectively. From the Figure 5.2(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. Figure 5.2(b) depicted the current distribution at 6.73 GHz and found that, current flowing in two direction on the upper patch and ground plane. This different length of currents is responsible for generating dual band resonance frequencies.
Table 5.1. Design specifications for proposed antenna geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_g$</td>
<td>40 mm</td>
<td>$W_1$</td>
<td>2 mm</td>
</tr>
<tr>
<td>$W_g$</td>
<td>40 mm</td>
<td>$L_2$</td>
<td>10 mm</td>
</tr>
<tr>
<td>$L$</td>
<td>40 mm</td>
<td>$\varepsilon_r$</td>
<td>4.7</td>
</tr>
<tr>
<td>$W$</td>
<td>2 mm</td>
<td>$h$</td>
<td>1.58 mm</td>
</tr>
<tr>
<td>$L_1$</td>
<td>20 mm</td>
<td>$\tan\theta$</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5.1. (a) Proposed antenna design (b) Fabricated antenna
5.2.2 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.

5.2.2.1 Data generation

The bandwidth of microstrip patch antenna is mainly depending on the length ($L$), width ($W$), height ($h$), and dielectric constant ($\varepsilon_r$) 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 $2 \leq \varepsilon_r \leq 4.7$ and antenna geometry is simulated using IE3D software. Simulated reflection coefficient ($S_{11}$) of the

Figure 5.2. Current distribution at frequency (a) 4 GHz (b) 6.73 GHz
proposed antenna geometry is recorded and their respective bandwidths for dual band are calculated whereas the other two parameters \( h \) and \( W \) are kept constant.

### 5.2.2.2 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 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. Figure 5.3 shows the structure of RBFNN model which have three layers. First one is the input layer consist of three source nodes with \( \varepsilon_r \), \( h \), \( w \) 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 computational units as the size of the training samples and each unit of hidden layer is mathematically described by radial basis function [46].

\[
\phi_j(x) = \phi\left(\|x - x_j\|\right), \quad j = 1, 2, \ldots, N
\]  

(5.1)

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 Figure 5.3 and defined by

\[
\phi_j(x) = \phi(x - x_j)
\]

(5.2)

\[
\phi_j(x) = \exp\left(-\frac{1}{2\sigma_j^2}\|x - x_j\|^2\right), \quad j = 1, 2, \ldots, N
\]

(5.3)

where \( \sigma_j \) 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.
Figure 5.3. Radial basis function neural network model

Figure 5.4. Number of epochs to achieve minimum mean square errors
Figure 5.4 shows the number of epochs to achieve minimum mean square errors (MSE) in case of RBF neural network. From the results of Figure 5.4, it is observed that the level of mean square error is found minimum with 188 numbers of epochs during the training of RBF neural network model.

5.2.3 Results and Discussion

Radial basis function neural network is tested with 21 sets of training data. Figures 5.5-5.6 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 Figures it is observed that error is minimized with 25 neurons in the hidden layer, 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 Figure 5.1(b). The reflection coefficient and radiation pattern of the fabricated antenna is measured using Agilent N5230 network analyzer and in anechoic chamber respectively.
Figure 5.5. Bandwidth of first band at 25 neurons

Figure 5.6. Bandwidth of second band at 25 neurons
5.2.3.1 Proposed antenna results

Figure 5.7 shows the variation in return loss with frequency for several heights of the used substrate glass epoxy. Figure 5.7 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 5.2 with respect to the variation of different heights.

Table 5.2. Antenna characteristics with the variation of substrate height (h)

<table>
<thead>
<tr>
<th>Substrate height (h)</th>
<th>Frequency (GHz)</th>
<th>S_{11} (BW%)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>h = 1.58 mm</td>
<td>4 GHz, 6.58 GHz</td>
<td>10.42 %, 9.42 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>h = 0.75 mm</td>
<td>4.26 GHz, 7.06 GHz</td>
<td>8.45 %, 13.72 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>h = 0.50 mm</td>
<td>4.32 GHz, 7.37 GHz</td>
<td>7.87 %, 14.65 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>h = 0.25 mm</td>
<td>7.67 GHz</td>
<td>4.21 %</td>
<td>Single band</td>
</tr>
</tbody>
</table>

Figure 5.7. Reflection coefficient variation for several heights of the substrate
Figure 5.8 shows the variation in reflection coefficient with 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 Figure 5.8 it is clear that the obtained bandwidth is wider for Bakelite ($\varepsilon_r = 3.3$) and RT Duroid ($\varepsilon_r = 2.32$) substrate than the comparison of glass epoxy substrate. In this work, substrate used is glass epoxy and the reason behind selecting this substrate is that it is easily available, efficient for wider range of microwave frequency upto 10 GHz and less costly than the other substrates. Table 5.3 shows the summarized data of proposed antenna characteristics with the variation in dielectric constant ($\varepsilon_r$) of substrate. This data is used for the testing of RBF neural network model. From the Table 5.3 it is observed that glass epoxy ($\varepsilon_r = 4.7$) substrate produces appropriate results which validate the ANN results.

Table 5.3. Antenna characteristics with the dielectric constant ($\varepsilon_r$) of substrate

<table>
<thead>
<tr>
<th>Dielectric constant ($\varepsilon_r$)</th>
<th>Frequency (GHz)</th>
<th>S$_{11}$ (BW%)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam ($\varepsilon_r = 1.07$)</td>
<td>8.83 GHz</td>
<td>4.27 %</td>
<td>Single band</td>
</tr>
<tr>
<td>RT Duroid ($\varepsilon_r = 2.32$)</td>
<td>4.74 GHz, 8.22 GHz</td>
<td>7.58 %, 17.72 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>Bakelite ($\varepsilon_r = 3.3$)</td>
<td>4.29 GHz, 7.42 GHz</td>
<td>9.49 %, 11.63 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>Glass epoxy ($\varepsilon_r = 4.7$)*</td>
<td>4 GHz, 6.58 GHz</td>
<td>10.42 %, 9.42 %</td>
<td>Dual band</td>
</tr>
</tbody>
</table>

Table 5.4. Antenna characteristics

<table>
<thead>
<tr>
<th>Proposed antenna</th>
<th>Frequency (GHz)</th>
<th>S$_{11}$ (BW %)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without ground plane</td>
<td>8.5 GHz</td>
<td>4.20 %</td>
<td>Single band</td>
</tr>
<tr>
<td>With ground plane (simulated)</td>
<td>4 GHz, 6.73 GHz</td>
<td>10.42 %, 9.42 %</td>
<td>Dual band</td>
</tr>
<tr>
<td>With ground plane (measured)</td>
<td>4 GHz, 6.73 GHz</td>
<td>10.03 %, 9.12 %</td>
<td>Dual band</td>
</tr>
</tbody>
</table>
Figure 5.8. Reflection coefficient variation for several dielectric materials

Figure 5.9. Reflection coefficient with and without ground plane
The reflection coefficient spectrum of proposed antenna is shown in Figure 5.9. 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 5.4. Figure 5.10 shows the comparative plot of gain and efficiency of the proposed antenna.

Table 5.5. Comparison of Simulated, ANN, and measured results for bandwidth

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bandwidth of first band</th>
<th>Bandwidth of second band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated</td>
<td>10.42 %</td>
<td>9.42 %</td>
</tr>
<tr>
<td>ANN</td>
<td>10.4012 %</td>
<td>9.4145 %</td>
</tr>
<tr>
<td>Measured</td>
<td>9.23 %,</td>
<td>9.12 %</td>
</tr>
</tbody>
</table>

![Figure 5.10. Comparative plot of gain and efficiency with frequency]
Figure 5.11. Radiation pattern at (a) 4 GHz (b) 6.73 GHz
The radiation patterns for \( E-H \) plane with resonant frequencies 4 GHz and 6.73 GHz are represented in Figure 5.11 (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.

### 5.3 MICROSTRIP LINE FEED TOPPLED H-SHAPED PATCH ANTENNA

#### 5.3.1 Simulated Antenna Design and Fabrication

This section shows the geometry formation process of proposed antenna. The proposed antenna of dimension \( L_g \times W_g \) is designed on FR4 substrate with dielectric constant \( \varepsilon_r = 4.4 \) and height \( h = 1.60 \) mm as shown in Figure 5.12(a). For the formation of proposed antenna geometry, firstly two strips of dimensions \( L_1 \times W \) and \( L_2 \times W \) are etched on the upper side of the rectangular patch at coordinate \((0, 0)\). Further, two vertical strips of dimension \( L_3 \times W \) and two horizontal strips of dimension \( L_4 \times W \) are etched at the coordinate \((+10, 0), (-10, 0)\) and \((0, +10), (0, -10)\) respectively. In the next step, six vertical strips of dimension \( L_5 \times W \) are etched at coordinates \((5, 10), (-5, 10), (5, -10), (-5, -10), (15, 0) \) and \((-15, 0)\) respectively on the upper side of the patch. Although the lower portion of the patch is fully grounded and covers dimensions of \( L_g \times W_g \), the microstrip line feed is used for the excitation of the proposed antenna. The necessary numerical analysis and suitable geometrical parameters of the proposed antenna are obtained with the aid of the electromagnetic simulation software IE3D, and the best design parameters are revealed in Table 5.6. The fabricated design of proposed antenna is shown in Figure 5.12(b). The current distribution of the proposed antenna is shown in Figures 5.13(a)-(b) and (c) at frequencies 1.8 GHz, 3.5 GHz, and 5.5 GHz respectively.
Table 5.6. Design specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_9$</td>
<td>40 mm</td>
<td>$L_5$</td>
<td>10 mm</td>
</tr>
<tr>
<td>$W_g$</td>
<td>40 mm</td>
<td>$W$</td>
<td>2 mm</td>
</tr>
<tr>
<td>$L_1$</td>
<td>40 mm</td>
<td>$h$</td>
<td>1.60 mm</td>
</tr>
<tr>
<td>$L_2$</td>
<td>40 mm</td>
<td>$\varepsilon_r$</td>
<td>4.4</td>
</tr>
<tr>
<td>$L_3$</td>
<td>20 mm</td>
<td>$\tan\phi$</td>
<td>0.002</td>
</tr>
<tr>
<td>$L_4$</td>
<td>20 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.12. (a) Microstrip line feed Toppled H-shaped patch antenna structure  
(b) Fabricated microstrip line Toppled H-shaped patch antenna
5.3.2 Results and Discussion

For triple band operation, the proposed antenna is fed by microstrip line feeding. The simulation of proposed antenna has been performed using method of moment based IE3D simulation software [25]. The proposed antenna design has been fabricated for the validation of simulated work. An SMA connector of 50 ohm impedance is connected for the excitation of the proposed antenna geometry. The reflection coefficient of proposed antenna has been measured using N5230 network analyzer. The detail information about designed antenna characteristics are discussed in this section.

Figure 5.14 shows the comparison of simulated and measured reflection coefficients at various frequencies. It is observed that the proposed antenna operates in triple frequency bands at 1.8 GHz (1.743 GHz – 1.857 GHz), 3.5 GHz (3.294 GHz – 3.7 GHz), and 5.5 GHz (5.205 GHz – 5.94 GHz)
and this happens because the adding of ground plane on proposed antenna, a coupling capacitance is generated between the upper patch and ground plane since radiating structure improves. These operating frequency bands meet the demands for PCS and WiMAX applications. From this figure it also reveals that the simulated and measured reflection coefficients (S\textsubscript{11} \leq -10 \text{ dB}) of proposed antenna are in good agreement, only minor discrepancy occurs because of the irregular fabrication and soldering joint losses which was not included during simulation.

Figure 5.15 shows the variation of reflection coefficient for different dielectric materials. It is observed that with decreasing the value of dielectric substrate from FR4 to foam, the resonant frequencies are shifted towards higher resonance side and the value of reflection coefficients increases. This happens because the dielectric constant of the substrate is directly proportional to the resonant frequency of patch antenna.

Figure 5.16 shows the variation in reflection coefficient for different heights of the material. It reveals that with decreasing the height from h=1.60 mm to h=0.13 mm, second and third band are shifted toward the higher resonance side whereas first band is shifted towards lower resonance side.

Figure 5.17 shows the plot for measured gain and efficiency of proposed antenna at various frequencies. The gain of the proposed antenna at operating frequencies 1.8, 3.5, and 5.5 GHz are found 4.44, 6.15, and 6.57 dBi respectively. The efficiency of proposed antenna is found 69.53%, 95%, and 88.15% at resonating frequencies 1.8, 3.5, and 5.5 GHz respectively.

Radiation pattern of proposed antenna is shown in Figures 5.18(a)-(b) and (c). It shows the comparative plot for E-H plane radiation pattern of proposed antenna at frequencies 1.8, 3.5, and 5.5 GHz respectively. From these figures, it is observed that the proposed antenna is radiating maximum power in broadside direction within the operating bands. The 3 dB beamwidth of proposed antenna are calculated as 58˚, 58.3˚, 52.7˚ for E-plane (E-\theta, \varphi=0˚) and 48˚, 49˚, 45˚ for H-plane (E-\theta, \varphi=90˚) at frequencies
**Figure 5.14.** Comparison of simulated and measured reflection coefficient variation at various frequencies

**Figure 5.15.** Reflection coefficient variation for several dielectric materials
Figure 5.16. Reflection coefficient variation for several heights of dielectric material

Figure 5.17. Measured gain and efficiency of proposed antenna at various frequencies
Microstrip Line Feed Toppled Shaped Patch Antennas
Figure 5.18. Comparative plot for radiation pattern at frequencies (a) 1.8 GHz (b) 3.5 GHz (c) 5.5 GHz

1.8, 3.5, and 5.5 GHz respectively. It means that, at 1.8, 3.5, and 5.5 GHz, antenna radiates most of the power at these specified beamwidths.

In this chapter two antennas i.e. Toppled T and H-shaped has been discussed for dual and multiband frequency operation. In the next chapter, effect of shorting wall on 2×4 MSA array using ANN will be presented.
REFERENCES


