CHAPTER 4

ANN AND ITS COUPLING WITH GA FOR ANTENNA DESIGN
4.1 Introduction

In this chapter, Artificial Neural Networks (ANNs) is used for design of microstrip antenna. Firstly, backpropagation algorithm is applied to calculate resonant frequency of rectangular microstrip antenna with shorting post. To further improve the backpropagation algorithm, Tunnel Based Artificial Neural Networks (ANNs) is also developed to calculate the radiation patterns of the antenna. In the second phase, ANN is used to improve Genetic Algorithm (GA) for problems those are not having a proper fitness function. The proposed technique of using ANN as fitness function of GA is applied to calculate the design parameters of a thick substrate rectangular microstrip antenna. A Multi-Layer Feed-Forward Neural Network is used as fitness function in a binary coded genetic algorithm. The results are in very good agreement with experimental findings.

4.2 Calculation of Resonant Frequency of Single Shorting Post Microstrip Patch Antenna

One of the major disadvantages of microstrip patch antenna is its inherent narrow bandwidth, which restricts its wide applications. A number of techniques have been developed for bandwidth enhancement[1-9].
Use of shorting pins[10] is a simple and efficient method to handle such problems. By changing the number and location of the shorting posts, the operating frequency can be tuned, and the polarization can also be changed. Figure 4.1 represents the schematic diagram of the single shorting post rectangular microstrip antenna. Depending on the position of the shorting post, the resonant frequency of the rectangular microstrip antenna can be tuned.

![Fig. 4.1 Rectangular Microstrip Patch Antenna with a Shorting Post](image)

The network 5x20x1 is trained by normal feed forward back-propagation algorithm having steepness of activation function, lambda(\(\lambda\)) = 1, learning constant(\(\eta\)) = 0.3 and, momentum factor(\(\alpha\)) = 0.1. In this case, all the four parameters are chosen by hit and trial method. The error vs. epoch for the training is shown in figure 2.10. The training time is found to be 889 seconds for an error tolerance of 0.05. The average error per pattern for four patterns is found to be 0.0482 GHz.
Fig. 4.2 No. of Cycles vs. Error

As shown in table 4.1, the results obtained by ANN are close to experimental data.

Table 4.1 Resonant Frequency of a Microstrip Antenna Using Single Shorting Pin Applying ANN

<table>
<thead>
<tr>
<th>$L_1/L$</th>
<th>$L$ (in cm)</th>
<th>$W$ (in cm)</th>
<th>$\varepsilon_r$</th>
<th>$h$ (in cm)</th>
<th>$f_r(\text{EXPT})$ (in GHz)</th>
<th>$f_r$ (Eqn. 10 off[10]) (in GHz)</th>
<th>$f_r(\text{Back-propagation})$ (in GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>6.2</td>
<td>9</td>
<td>2.55</td>
<td>0.16</td>
<td>1.594</td>
<td>1.64</td>
<td>1.619</td>
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<td>0.3</td>
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<td>3.014</td>
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</tbody>
</table>

* The radius of the metallic post ($r_0$) = 0.064 cm
4.3 Application of Tunnel-Based ANN on Microstrip Patch Antenna Design

Backpropagation algorithm i.e. the gradient decent method is modified using the tunneling technique. The concept of tunneling[11,12] technique is based on violation of Lipschitz condition[12] at equilibrium position, which is governed by the fact that any particle placed at small perturbation from the point of equilibrium will move away from the current point to another within a finite amount of time. The tunneling is implemented by solving the differential equation given by[12],

$$\frac{dw}{dt}=p(w-w^*)^{1/3}$$  \hspace{1cm} (4.1)

Where, ‘p’ and ‘w*’ represent the strength of learning and last local minima for ‘w’ respectively. The differential equation is solved for some time till it attains the next minima position. To start with the training cycle, some perturbation is added to the weights. Then, the sum of square errors(E) for all the training patterns is calculated. If it is greater than the last minima than it is tunneled according to above equation. If the error is less than the last local minima than the weights are updated according to the relation,

$$\Delta w(t)=-\eta \nabla E(t)+\alpha \Delta w(t-1)$$  \hspace{1cm} (4.2)

Where, ‘\eta’ is called learning factor and ‘\alpha’ is called momentum factor. ‘t’ and ‘(t-1)’ indicate current and the most recent training steps respectively. This technique is validated by implementing it for calculating radiation pattern of a wide-band microstrip patch antenna as shown in figure 4.1.
Fig. 4.3 Geometry of the Multi-Slots Hole-Coupled Microstrip Antenna

(The antenna parameters are $L=45$ mm, $W=71$ mm, $h=2$ mm, $L_s=17.5$ mm, $W_s=04$ mm, Feed position $(x_f, y_f) = (0.75$ mm, $69$ mm))

The antenna has been designed on a substrate of thickness 2 mm with $\varepsilon_r=2.2$. The patch size is characterized by length, width and thickness ($L$, $W$, $h$) and is fed by a coaxial probe at position $(x_f, y_f)$. A hole of 0.2mm diameter has been made at location $(x_n, y_n)$ for impedance matching. Four slots are incorporated into this patch and are positioned on both sides of feed position. The structure resembles to the geometry as if an E-shaped patch has been joined with another inverted E-shaped patch. The slot length ($L_s$), width ($W_s$) and position ($P_s$) are important parameters in controlling the bandwidth. Due to
slots, the length of the current path is increased\cite{13}, which leads to additional inductance in series. Hence, the wide band is generated as resonant circuits get coupled. The slots aggregate the currents, which give additional inductance, which is controlled by patch width (W). For impedance compensation and for better matching, a hole is made at $(x_h=6.75\, \text{mm}, y_h=35\, \text{mm})$. The approach of creating a hole gives the flexibility of changing the reactive component for impedance matching. IE3D software is used to calculate the return loss and VSWR of the considered antenna.

A multilayer $2x80x1$ structure, shown in figure 4.4, is used for training the network. The other network parameters used are as follows,

The network is trained by taking 36 patterns each for 6.0GHz, 6.5GHz, 10.5GHz and 12GHz. The training time required is 7.35 minutes. The network is tested for 480 patterns. Figure 4.3 shows the radiation at 6GHz and 10.5GHz whereas Figure 4.4 shows the radiation pattern at 6.5GHz and 12GHz.

<table>
<thead>
<tr>
<th>Noise Factor=0.004</th>
<th>Time Step for Integrating for the Differential Equation=$5\times10^{-15}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum Factor=0.075</td>
<td>Strength of Learning for Tunneling=0.08</td>
</tr>
<tr>
<td>Learning Constant=0.08</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 4.4 Network Architecture Showing Angle and Frequency as Input and Gain as Output

Fig. 4.5 Radiation Pattern for E-Total, theta=0 at 6 GHz and 10.5 GHz
Fig. 4.6 Radiation Pattern for E-Total, theta=0 at 6.5GHz and 12.0GHz

The total average errors at different frequencies are 6GHz is 0.0408, at 6.5GHz is 0.0520241, at 10.5 GHz is 0.0745005 and at 12 GHz is 0.0181725. Experimental measurements are carried out to see the radiation patterns at 10.5GHz and at 12GHz. The results are in good agreement with the results of IE3D and with ANN.

The variation of slot parameters, hole size and positions gives the flexibility to shift the frequency and match the impedance, which is a notable feature of the referred antenna.
4.4 ANN Used as Fitness Function of GA and Its Application to Microstrip Patch Antenna Design

Over the years, genetic algorithm has been applied in many applications. But lack of proper fitness function acts as a hindrance for its wide spread application in many cases. Often in electromagnetics, the objective function (fitness function) arises for optimization is multimodal, stiff and non-differentiable. In addition, they are computationally expensive to evaluate. Tentativeness of the objective function cannot be relied upon when accuracy cannot be compromised. The deterministic optimization technique like Monte Carlo technique, simulated annealing and hill climbing, or evolutionary optimization technique like Genetic algorithm (GA) [14-16,23] mostly rely upon objective function, without which the optimization technique has no meaning. Here a new class of objective function formulation technique is presented in which trained Artificial Neural Networks (ANN) is used as fitness function. The presented technique can be used everywhere particularly in those cases, where the objective function formulation is difficult, or the objective function is erroneous.

4.4.1 Application on Microstrip Patch Antenna

A novel technique of using Artificial Neural Networks as fitness function of Genetic algorithm to calculate the design parameters of a thick substrate rectangular microstrip antenna is presented here for
which there is no closed form mathematical formula to calculate the resonant frequency. A Multi-Layer Feed-Forward Neural Network is used as fitness function in a binary coded genetic algorithm. It is seen that the results obtained by this method are closer to experimental value compared to earlier results obtained by curve fitting method. To validate this, the results are compared with experimental values for five fabricated antennae. The results are in very good agreement with experimental findings.

With $h/\lambda_0 > 0.0815$, the properties of the patch antenna changes drastically[24,25], where 'h' is the thickness of the substrate and $\lambda_0$ is the free space wavelength. The standard formulae available in the literature are valid for $h/\lambda_0 < 0.0815$. So, for $h/\lambda_0 > 0.0815$, the designer, thus, forced to obtain the physical characteristics by trial and error method or numerical method. But these formulae are derived by curve fitting method which can be extrapolated to a certain extent only. Thus, there is a need for a robust numerical approximation for the calculation of the dimensions. A typical microstrip antenna with length (L), width (W), height (h), and the feed point location (a) are shown in the figure 3.1.

The approach[26] is basically a two step calculation procedure. In the first step a suitable network is selected and trained for a set of training data. After successful training the network will learn the input-output relation among length, width, thickness, permittivity and
resonant frequency of the antenna. In the second step the network will be used as objective function and GA will be used for calculation of the optimized dimension.

4.4.2 Training Phase

The back propagation algorithm, using gradient decent method is used for training the network. A three layers neural network, consisting of four input neurons, thirty hidden neurons and one output neuron (i.e 4 x 30 x 1) has been used. For this network, length, width, substrate thickness and dielectric constant of the substrate are taken as inputs where as, resonant frequency is taken as output. The proposed model is as shown in the figure 4.7.

![Network Structure](image_url)

**Fig. 4.7 Network Structure**
Twelve patterns from [24] are taken for training the networks and rest five patterns are used for testing the networks and the ANN based GA code. The parameters considered for training the network are,

\begin{align*}
\text{Noise factor parameters} & = 0.0003 \\
\text{Learning Constant (parameter)} & = 4 \\
\text{Momentum factor} & = 0.0205.
\end{align*}

Noise factor of 0.0003 is used during training of ANN to increase its generalization capability. The number of hidden neurons and various parameters are chosen by hit-and-trial method.

4.4.3 Optimization Phase

The two independent variables to be optimized are the length and width of the antenna. The population size of 20 individuals, and 200 generations are produced. Roulette wheel selection procedure is adopted to select new population. The probability of crossover is set to 0.7, while the probability of mutation is equal to 0.01. The fitness of the selected population is calculated from the trained neural network. The process is repeated until the termination criterion is met. The flow chart of the proposed algorithm is presented in figure 4.6. The fitness of an individual is decided according to following relation,

\begin{equation}
\text{Fitness} = f(L, W, \epsilon, h) = 1/(1+|f_e - \text{desired frequency}|) = 1/(1+|\text{output of ANN} - \text{desired frequency}|)
\end{equation}

(4.3)
Fig. 4.8 Flow chart of the Proposed Algorithm

The optimized design parameters of five antennae considered for testing is tabulated in Table 4.2. Out of three inputs, one is dielectric constant \( (\varepsilon_r = 2.55) \) of the substrate. The other two inputs are listed in 2\(^{nd}\), 3\(^{rd}\) column. The experimental dimensions of length and width are
shown in 4th and 7th column respectively, while optimized output of our GA-ANN based dimensions are listed in 6th and in the last column of the table. By using empirical formulae derived by curve fitting method [24], the average error in calculating length and width of thick substrate microstrip antenna is found to be 0.06 and 0.074 respectively where as, the presented method shows an average error of 0.032 for length and that of for width is 0.018. Thus, an ANN coupled GA gives better results compared to formulae derived in [24].

**Table 4.2 Dimensions of Thick Substrate Rectangular Microstrip**

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* The radius of the metallic post ($r_0$) = 0.064cm

The measure of accuracy of the solution obtained by GA depends directly upon the efficient training of the neural networks. So, care must be taken for efficient training of the network. Cases where, there is no
accurate theoretical formulation for objective function, this technique can be used for optimization purpose.

Simultaneous optimization of dielectric constant, height of the substrate and dimensions etc. is possible in the proposed method where as, in conventional method it is either computationally complex or, not possible. The results obtained by the ANN coupled GA is compared with experimental results. The results are in very good agreement with experimental findings.

4.5 Conclusion

A back-propagation algorithm is used to calculate the resonant frequency of single shorting post tunable microstrip antenna. This technique to calculate resonant frequency of shorted microstrip antenna seems to be a simple, inexpensive and highly accurate method. Accuracy can be improved by choosing smaller error tolerance and/or training the network for more number of iterations while evaluating the fitness value.

The radiation patterns of the antenna calculated by Tunnel based Artificial Neural Networks (ANNs) is compared with experimental results measured. The experimental results are in good agreement with the simulated results of IE3D and that of ANNs. This simple method saves computational time considerably giving better accuracy.
In proposed method of coupling ANN with GA, the simulation time is very less as compared to the simulation time of methods like Method of Moments (MoM), Finite Difference Time Domain (FDTD) and Finite Element Technique (FET) without compromising with the error. The accuracy of the proposed model can be increased by using a more effective ANN algorithm. Further, the accuracy can be increased by taking more experimental results for training the artificial neural network. This method may go a long way in improving the ANN based techniques to solve problems like array factor correction, cross polarization reduction, band width enhancement and array optimization etc.
References


24. M. Kara, "The Resonant Frequency of Rectangular Microstrip Antenna Elements with various Substrate Thicknesses",