Design and Analysis of Microstrip Patch Antennas Using Soft Computing

Ashish Kumar Singh
Assistant Professor, Department of Physics
Arunachal University of Studies, Namsai, Arunachal Pradesh, India

Mahesh Shankar Pandey
Assistant Professor, Department of Electronics & Communication
UIT, Shahdol, Madhya Pradesh, India

Abstract- Microstrip patch antenna used to send onboard parameters of article to the ground while under operating conditions. The aim of the project is to design and fabricate an probe-fed Rectangular Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), and substrate parameters relative Dielectric constant (εr), substrate thickness (t) on the Radiation parameters of Bandwidth and Beam-width through the Neural network. This paper presents the general design of Microstrip antennas using artificial neural networks for rectangular patch geometry. The design consists of synthesis in the forward side and then analyzed as the reverse side of the problem. In this work, the neural network is employed as a tool in design of Microstrip antennas. The Neural network Training algorithms are used in simulation of results for training the samples to minimize the error and to obtain the geometric dimensions with high accuracy for selective band of frequencies.

Keywords – Cloud computing, Microstrip patch antenna, Neural Network, Matlab Software, IE3D.

I. INTRODUCTION

Communication between humans was first by sound through voice. With the desire for slightly more distance communication came, devices such as drums, then, visual methods such as signal flags and smoke signals were used. These optical communication devices, of course, utilized the light portion of the electromagnetic spectrum. It has been only very recent in human history that the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of humankind's greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource.

Waves on Microstrip: The mechanisms of transmission and radiation in a microstrip can be understood by considering a point current source (Hertz dipole) located on top of the grounded dielectric substrate (figure 1.) This source radiates electromagnetic waves. Depending on the direction toward which waves are transmitted, they fall within three distinct categories, each of which exhibits different behaviors.

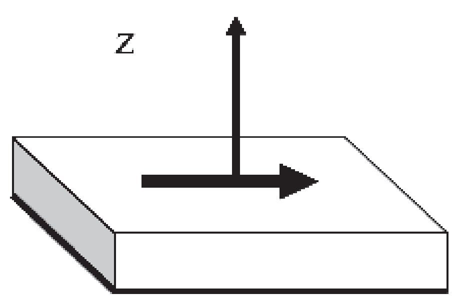


Figure 1. Hertz dipole on Microstrip Substrate

Antenna Characteristics: An antenna is a device that is made to efficiently radiate and receive radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for your application as follows:

- Antenna radiation patterns
- Power Gain
- Directivity
- Polarization

Microstrip patch antenna: In its most fundamental form, a Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

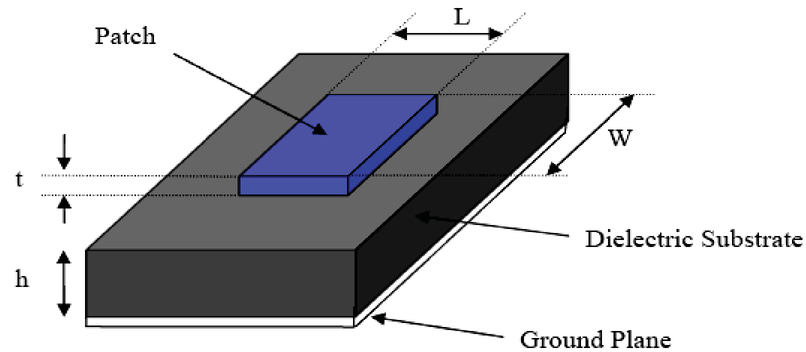


Figure 2. Structure of a Microstrip Patch Antenna

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

Feed Techniques: Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

Microstrip Line Feed: In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 3. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

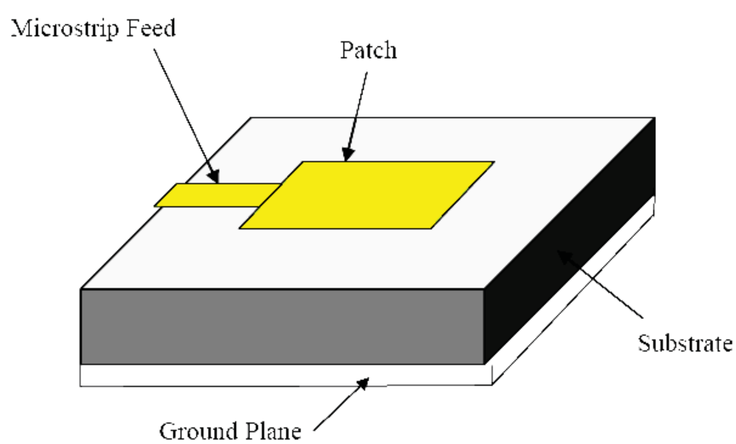


Figure 3. Microstrip Line Feed

II. METHODS OF ANALYSIS

The preferred models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

Transmission Line Model: This model represents the microstrip antenna by two slots of width *W* and height *h*, separated by a transmission line of length L. The microstrip is essentially a nonhomogeneous line of two dielectrics, typically the substrate and air.

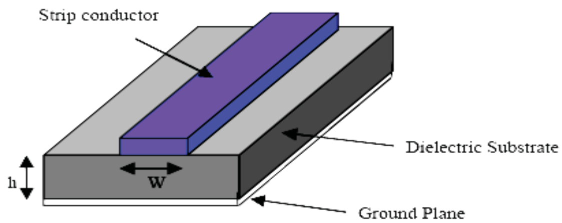


Figure 4. Microstrip Line

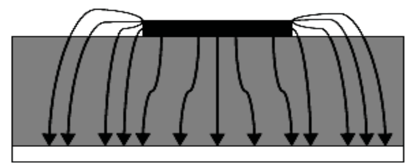


Figure 5. Electric Field Lines

Hence, as seen from Figure 4, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less then ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 5. above. The expression for ε_{reff} is given by Balanis as:

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

Where ε_{reff} = Effective dielectric constant
ε_r = Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch

Cavity Model: Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages. Specifically, it is useful for patches of rectangular design and it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below.

In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates ($h << \lambda$).

• Since the substrate is thin, the fields in the interior region do not vary much in the *z* direction, i.e. normal to the patch.

· The electric field is *z* directed only, and the magnetic field has only the transverse components *Hx* and *Hy* in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and the bottom.

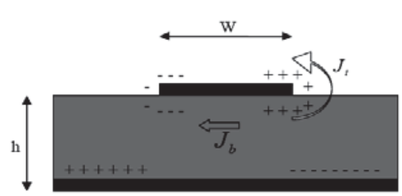
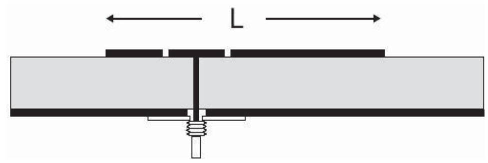


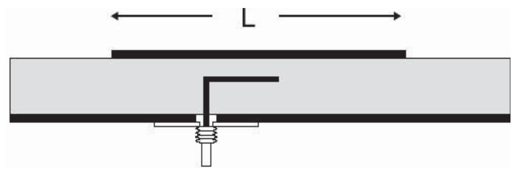
Figure 6. Charge distribution and current density creation on the microstrip patch

III. IMPROVING PERFORMANCE:

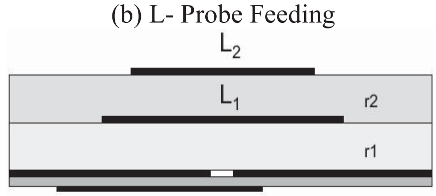
Much research has been devoted to improving the performance characteristics of the microstrip antenna. To improve bandwidth, the use of thick low-permittivity (e.g., foam) substrates can give significant improvement. To overcome the probe inductance associated with thicker substrates, the use of capacitive-coupled feeds such as the top-loaded probe or the L-shaped probe shown in Figure 7. a and Figure 7. b may be used. Alternatively, the aperture coupled fed shown in Figure 3.3c may be used, which also has the advantage of eliminating spurious probe radiation. To increase the bandwidth even further, a stacked patch arrangement may be used, in which a parasitic patch is stacked above the driven patch. This may be done using either a probe feed or, to obtain even higher bandwidths, using an aperture-coupled feed (Figure 7. c).



(a) Top Loading Probe Feeding



(b) L- Probe Feeding



(c) Aperture Coupled Feeding

Figure 7. Feed Types

Another variation of the microstrip antenna that has been introduced recently is the “reduced surface wave” microstrip antenna shown in Figure 8.

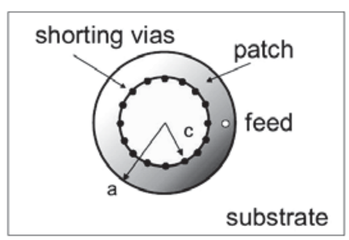


Figure 8. Reduced surface wave microstrip antenna

This design is a variation of a circular patch, with an inner ring of vias that creates short-circuit inner boundary. By properly selecting the outer radius, the patch excites very little surface-wave field, and also only a small amount of lateral (horizontally propagating) radiation. The inner short-circuit boundary is used to adjust the dimensions of the patch cavity (between the inner and outer boundaries) to make the patch resonant. The reduced surface-wave and lateral radiation result in less edge diffraction from the edges of the supporting ground plane, giving smoother patterns in the front-side region and less radiation in the backside region. Also, there is less mutual coupling between pairs of such antennas, especially as the separation increases.

Training of Artifcial Neural Networks: A neural network has to be configured such that the application of a set of inputs produces (either 'direct' or via a relaxation process) the desired set of outputs. Various methods to set the strengths of the connections exist. One way is to set the weights explicitly, using a priori knowledge. Another way is to 'train' the neural network by feeding it teaching patterns and letting it change its weights according to some learning rule.

.

IV. SOFTWARE USED

Matlab Software: MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. The MATLAB is in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology.

MATLAB is a numerical computing environment and fourth generation programming language. Developed by The Math Works, MATLAB allows matrix manipulation, plotting of dynamic and embedded systems.

Structures: MATLAB supports structure data types. Since all variables in MATLAB are arrays, a more adequate name is "structure array", where each element of the array has the same field names. In addition, MATLAB supports dynamic field names (field look-ups by name, field manipulations etc). Unfortunately, MATLAB JIT does not support MATLAB structures; therefore just a simple bundling of various variables into a structure will come at a cost.

IE3D: IE3D is a full-wave, method-of-moments based electromagnetic simulator solving the current distribution on 3D and multilayer structures of general shape. It has been widely used in the design of MMICs, RFICs, LTCC circuits, microwave/millimeter-wave circuits, IC interconnects and packages, HTS circuits, patch antennas, wire antennas, and other RF/wireless antenna.

V. MICROSTRIP PATCH ANTENNA DESIGN AND RESULTS

This chapter, the procedure for designing a rectangular microstrip patch antenna is explained. Next, a compact rectangular microstrip patch antenna is designed for use in cellular phones. Finally, the results obtained from the simulations are demonstrated.

*Design for Microstrip Antenna***:**In this work, the patch geometry of the microstrip antenna is obtained as a function of input variables, which are height of the dielectric material (*h*), dielectric constants of the substrate material (ε*r*), and the resonant frequency (*fr*), using ANN techniques (Figure 10). Similarly, in the analysis ANN, the resonant frequency of the antenna is obtained as a function of patch dimensions (*W, L*), height of the dielectric substrate (*h*), and dielectric constants of the material (ε*r*) (Figure 11). Thus, the forward and reverse sides of the problem will be defined for the rectangular patch geometry in the following subsections.

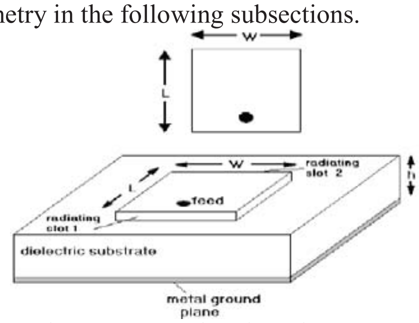


Figure 9. Rectangular Microstrip Antenna

The forward side of the problem: The synthsisANN: The input quantities to the ANN black-box in synthesis (Figure 9) can be ordered as:

• *h*: height of the dielectric substrate;

• ε*r* : electrical properties of the dielectric substrate,

where ε*r* is the permittivity in the x and y directions of the dielectric material used in the system, respectively;

• *fr* : resonant frequency of the antenna.

The following quantities can be obtained from the

output of the black-box as functions of the input variables:

• *W* : width of the patch;

• *L*: length of the patch:

. d: distance between indet depth and feed line**:**

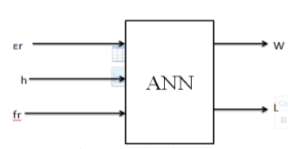


Figure 10. The Synthesis of ANN model

The reverse side of the problem: The analysis ANN: In the analysis side of the problem, terminology similar to that in the synthesis mechanism is used, but the resonant frequency of the antenna is obtained from the output for a chosen dielectric substrate and patch dimensions at the input side as shown in figure 11.

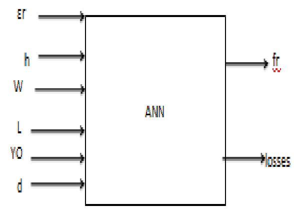


Figure 11. The Analysis of ANN model

Design Specifications: The three essential parameters for the design of a rectangular Microstrip Patch Antenna:

- Frequency of operation (*fo*): The resonant frequency of the antenna must be selected appropriately. The Mobile Communication Systems uses the frequency range from 2100-5600 MHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for my design is 6.1 GHz.
- Dielectric constant of the substrate (*εr*): The dielectric material selected for our design is RT
- Duroid which has a dielectric constant of 2.6. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
- Height of dielectric substrate (*h*): For the microstrip patch antenna to be used in cellular
- phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as .8 mm.

Hence, the essential parameters for the design are:

- *fr* = 6.1 GHz
- ε*r* = 2.6
- *h* = .8 mm

*Step 1: Calculation of the Width (W):*The width of the Microstrip patch antenna is given as:

$$W=\frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Substituting *c* = 3.00e+008 m/s, ε*r* = 2.6 and *fr* = 6.1 GHz, we get: *W* **= 0.01832 m = 18.32 mm**

Step 2: Calculation of Effective dielectric constant (εreff): The effective dielectric constant is:

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

Substituting ε*r* = 2.6, *W* = 18.32 mm and *h* = .8 mm we get: ε*reff* = **2.448**

Step 3: Calculation of the Effective length (Leff): The effective length is:

$$L_{\mathrm{eff}}=\frac{c}{2f_0\sqrt{\varepsilon_{\mathrm{reff}}}}$$

Substituting ε*reff* = 2.448, *c* = 3.00e+008 m/s and *fr* = 6.1 GHz we get: ***Leff*** **= 0.0161 m = 16.1 m**

Step 4: Calculation of the length extension (ΔL): The length extension is:

$$\Delta L=0.412h\frac{(\varepsilon_{\mathrm{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{\mathrm{reff}}-0.258)\left(\frac{W}{h}+0.8\right)}$$

Substituting ε*reff* = 2.448, *W* = 18.32 mm and *h* = .8 mm we get: Δ*L* **= 0.6198 mm**

Step 5: Calculation of actual length of patch (L): The actual length is obtained by:

$$L=L_{\mathrm{eff}}-2\Delta L$$

Substituting *Leff* = 16.1 mm and Δ*L* = 0.6198 mm we get: *L* **= 14.9mm**

Step 7: Determination of Inset feed depth (y0): An inset-fed type feed is to be used in this design. The feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point.In this case we use formula to obtain the optimum feed depth, where the return loss (R.L) is most negative (i.e. the least value). According to there exists a point along the length of the patch which gives the minimum return loss.

Rin (y = y 0) = Rin (y = 0) cos4 (π*y0/L)
Where, Rin (y=0) = 0.5 * (G1 ± G12)

$$Z_c = \frac{60}{\sqrt{\varepsilon_{reff}}} \ln\left[\frac{8h}{W_0} + \frac{W_0}{4h}\right] \qquad \frac{W_0}{h} \le 1$$

$$Z_c = \frac{120}{\sqrt{\varepsilon_{reff}}\left[\frac{W_0}{h} + 1.393 + 0.667\ \ln\left(\frac{W_0}{h} + 1.444\right)\right]} \qquad \frac{W_0}{h} > 1$$

Where

$$G_1 = \frac{1}{90}\left[\frac{W}{\lambda_0}\right]^2 \qquad W \ll \lambda_0$$

$$G_1 = \frac{1}{120}\left(\frac{W}{\lambda_0}\right) \qquad W \gg \lambda_0$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{K_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(K_0 L \sin\theta)(\sin\theta)^3\ d\theta$$

Using the first equation (assuming that ZC in the second equation is 50 Ω) where Rin (y=y0) = 50 Ω we get: **y0 = 3.8 mm**

Rectangular patch antenna dimensions are:,

1. Dielectric constant (εr) = 2.6
2. Frequency (fr) = 6.1 GHz.
3. Height (h) =.8 mm.
4. Velocity of light (c) = 3×108 $ms^{-1.}$
5. Practical width (W)= 18.32mm.
6. Practical Length (L) L = 14.9 mm.
7. Feed line width (W_0) = 2.2mm.
8. inset feed length(Y_O)= 3.8mm.

VI. DESIGN AND RESULTS

The software used to model and simulate the Microstrip patch antenna is Zeland Inc's IE3D. IE3D is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the *S*11 parameters, VSWR, current distributions as well as the radiation patterns.

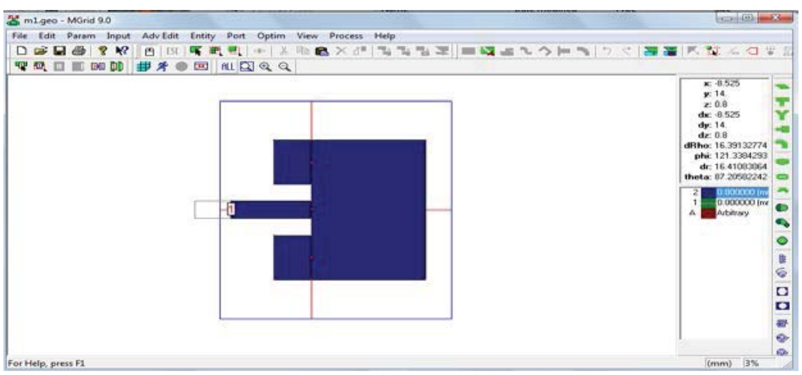


Figure 12. Microstrip patch antenna designed using IE3D

Return Loss: The inset feed used is designed to have an inset depth of 3.8mm, feed-line width of 2.2mm and feed path length of .8mm. A frequency range of .4-12 GHz is selected and 100 frequency points are selected over this range to obtain accurate results.

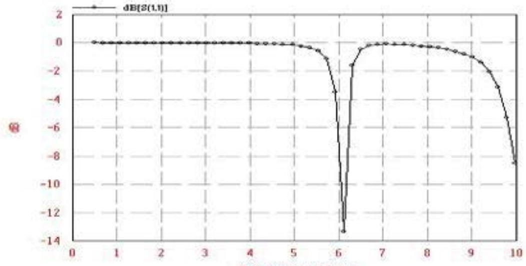


Figure 13. S-parameter plot for Return loss v/s frequency

Table and result:

Ant. Model	Microstrip width line W0	Inset feed depth Y0	Distance b/w Y0 & W0	Losses in dB	Fre. in GHz
M1	2.2	3.8	2.2	-13.4	6.1
M2	2.2	3.7	2.2	-17	6.1
M3	2.2	3.6	2.2	-12.1	6.1
M4	2.2	3.4	2.2	-14	6.2
M5	2.2	3.8	2.5	-14	6.1
M6	2.2	3.8	2.4	-12.9	6.1
M7	2.2	3.8	2.3	-11.1	6.1
M8	2.2	3.8	2.1	-9.3	6.1
M9	2.2	3.7	2	-14	6.1
M10	2.2	3.6	2	-14.2	6.1

In this table, We change the value between inset feed depth(Y_O) & d(distance between inset feed Y_o & feed line). We get data in losses(dB) & frequency(GHz) from change the value of Y_o and d.

Building Neural Networks for Rectangular Microstrip Antenna: In this work, both Multilayer Perceptron (MLP) and Radial Basis Function (RBF) networks are used in ANN models. The structures of these ANNs are described briefly below.

Multilayer Perceptron Networks: MLP are feed forward neural networks trained with the standard back propagation algorithm. They are supervised networks and so they require a desired response to be trained. They learn how to transform input data into a desired response, and so they are widely used for pattern classification. With 1 or 2 hidden layers, they can approximate virtually any input output map. They have been shown to approximate the performance of optimal statistical classifiers in difficult problems. Most neural network applications involve MLP. The basic MLP building unit is a simple model of artificial neurons. This unit computes the weighted sumof the inputs plus the threshold weight and passes this sum through the activation function (usually sigmoid). In a multilayer perceptron, the outputs of the units in one layer form the inputs to the next layer. The weights of the network are usually computed by training the network using the back propagation algorithm.

Structures of the neural networks: The MLP network, which has a configuration of 2 input neurons, 3 and 4 neurons in 2 hidden layers, and 2 output neurons with learning rate = 0.1, goal = 0.001, was trained for 500 epochs. Hyperbolic tangent sigmoid and linear transfer functions were used in MLP training. MLP models were trained with almost all network learning algorithms

Analysis of neural network for Microstrip patch antenna: The four-layer network has one output layer (layer 3), two hidden layer 3,4 neurons (layer 2) and one input layer (layer 1). Input and output layer consists of two neurons .inputs losses & freq. are applied at the input neurons while outputs insert feed y_0 and d are obtained from output neurons. A constant input 1 is fed to the biases for each neuron. Note that the outputs of each intermediate layer are the inputs to the following layer. A layer that produces the network output is called an output layer. Below Figure shows the neural network training graph results for the analysis of microstrip patch antenna. it is clear from this figure ,training performs in 500 epochs . We pass the full set of input samples through the neural network to compute the least squared error function we will use in the back propagation of the errors step. Each such pass is called an *epoch*. From this figure it is clear that error minimize between 10^1 to nearly 10^{-1} approximate.

Input value: Losses = -17dB; Freq= 6.1(GHz)
Losses= -18.1dB; Freq=6.4(GHz)

Above input value are used in the ANN model and we get output by the ANN.

Output value: $\mathbf{Y_0}$=3.6641mm**;** **d=**2.1750mm
$\mathbf{Y_0}$**=**3.4007mm**;** **d=**3.8837mm

From this value, we make a rectangular Microstrip antenna using IE3D & get simulation.

Input value: Losses = -17dB; Freq= 6.1(GHz)
Output value: $\mathbf{Y_0}$=3.6641mm**;** **d=**2.1750mm

IInd values
Input value: Losses= -18.1dB; Freq=6.4(GHz)
Output value: $\mathbf{Y_0}$**=**3.4007mm**;** **d=**3.8837mm

When we compare both of results (IE3D&ANN). These results are same. Therefore general design procedure for the microstrip antennas is also suggested using artificial neural networks.

VII. CONCLUSION AND FUTURE SUGGESTION

In this work, the Artificial Neural Network is employed as a design tool for the microstrip antennas. In this design one can obtain the resonating frequency with very high accuracy. Finally, in this work a general design procedure for the microstrip antennas is also suggested
using artificial neural networks.

Future Suggestion: In Microstrip antenna, it is very important to take the feed technique the impedance and the substrate is the main parameters into consideration. The proper position to terminate the Feed line also affects the performance of the antenna. As said different type of feed technique affects the performance of the antenna. The difference between two feed techniques Co-axial feed and Microstrip feed line is shown in the project and the results implies the performance of the antenna.

In future other different type of feed techniques can be used to calculate the overall performance of the antenna without missing the optimized parameters in the action. Extensively and exclusively focusing on the area of different design methods especially in enhancing the impedance bandwidth, and the efficiency.

REFERENCES

[1] C. A. Balanis, “Antenna Theory, Analysis and Design”, JOHN WILEY & SONS, INC, New York 1997.
[2] R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, “Microstrip Antenna Design Handbook”, ARTECH HOUSE, Boston 2001.
[3] S. Silver, “Microwave Antenna Theory and Design”, McGRAW-HILL BOOK COMPANY, INC, New York 1949.
[4] D. M. Pozar and D. H. Schaubert, Microstrip Antennas: The Analysis and Design of
[5] Microstrip Antennas and Arrays, IEEE Press, 1995.
[6] K. F. Lee, Ed., Advances in Microstrip and Printed Antennas, John Wiley, 1997.
[7] F. E. Gardiol, “Broadband Patch Antennas,” Artech House.
[8] D. R. Jackson and J. T. Williams, “A comparison of CAD models for radiation from
[9] rectangular microstrip patches,” Intl. Journal of Microwave and Millimeter-Wave
[10] Computer Aided Design, Vol. 1, No. 2, pp. 236-248, April 1991.
[11] K. Guney, S¸. Sa˘gıro˘glu, M. Erler, “Generalized neural method to determine resonant frequencies of various microstrip antennas”, International Journal of RF and Microwave Computer-Aided Engineering, Vol. 12, No. 1, pp. 131-139, January 2002.
[12] R.K. Mishra, A. Patnaik, “Neural network-based CAD model for the design of square-patch antennas”, Antennas and Propagation, IEEE Transactions, Vol. 46, No. 12, pp. 1890 –1891, December 1998.
[13] S. Devi, D.C. Panda, S.S. Pattnaik, “A novel method of using artificial neural networks to calculate input impedance of circular microstrip antenna”, Antennas and Propagation Society International Symposium, Vol. 3, pp. 462 – 465, 16-21 June 2002.
[14] K. G¨uney, N. Sarıkaya, “Artificial neural networks for calculating the input resistance of circular Microstrip antennas”, Microwave and Optical Technology Letters, Vol. 37, No. 2, pp. 107-111, 20 April 2003.
[15] G. Angiulli, M. Versaci, “Resonant frequency evaluation of microstrip antennas using a neural-fuzzy approach”, Magnetics, IEEE Transactions, Vol. 39, No. 3, pp. 1333 –1336, May 2003.
[16] R.K. Mishra, A. Patnaik, “Neurospectral computation for input impedance of rectangular microstrip antenna”, Electronics Letters, Vol. 35, No. 20, pp. 1691 – 1693, 30 Sept. 1999.
[17] R.K. Mishra, A. Patnaik, “Designing rectangular patchantenna using the neurospectral method”, Antennas and Propagation, IEEE Transactions, Vol. 51, No. 8, pp. 1914 –1921, Aug. 2003.
a. Patnaik, R.K. Mishra, G.K. Patra, S.K. Dash, ”An artificial neural network model for effective dielectric constant of microstrip line,” *IEEE Trans. on Antennas Propagation,* Vol. **45,** no. **11,** p. **1697,** November 1997**.**
[18] D. Karaboga, K. Guney, S. Sagıroglu, M. Erler, “Neural computation of resonant frequency of electrically thin and thick rectangular microstrip antennas”, Microwaves, Antennas and Propagation, IEEE Proceedings, Vol. 146, No. 2, pp. 155 – 159, April 1999
[19] F. Peik, G. Coutts, R.R. Mansour,COM DEV, Cambridge, ON, Canada, Application of neural networks in microwave circuit modeling ,Electrical and computer Engineering,1998,IEEE Canadian Conference, Vol-2,24-28 May 1998, pages:928-931
[20] S. Devi, D.C. Panda, S.S. Pattnaik, “A novel method of usingartificial neural networks to calculate input impedance of circular microstrip antenna”, Antennas and Propagation Society International Symposium, Vol. 3, pp. 462 – 465, 16-21 June 2002.