CHAPTER 1

REVIEW OF MICROSTRIP PATCH ANTENNA AND SOFT COMPUTING TECHNIQUES
1.1 Introduction

Microstrip antennas proposed by Deschamp in the year 1953[1], have gained a great attention in last few decades. Due to Its advantages like, low profile, low cost, ease of construction, conformal geometry and flexibility in terms of radiation pattern, gain and polarization etc. Microstrip patch antennas are also used in most of the modern handsets, personal digital devices and laptop computers[2,3,4]. It is a potential radiator for miniaturized portable or hand-held devices. Many methods have been developed for analysis of microstrip antenna[4,5]. They fall in to two broad categories: approximate methods and full wave methods. The approximate method include the transmission line model and cavity model. The full wave methods that can be used to model microstrip patch antennas are the method of moments (MoM), the finite element method(FEM) and the finite-difference time-domain(FDTD)method.

1.1.1 Transmission Line Model

Microstrip antennas have a physical structure derived from microstrip transmission lines [6-9]. Therefore, a transmission-line model is one of the most obvious choices for the analysis and the design of microstrip antennas.
The transmission line model representation of the microstrip antenna is shown in figure 1.1. The microstrip patch antenna is represented by two slots, separated by a transmission line of length ‘L’ and open circuited at both the ends. Along the width of the patch, the current is minimum and voltage appears maximum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane. The fields vary along the non-radiating edge of the patch, which is approximately half a wave length, and remain constant across the width. Variation of fields along the length depends on the propagation constant of the line. Radiation occurs mainly due to the fringing fields at the open ends.

However, this model is often regarded as over simplified and somewhat outdated[10]. This is true for the original, simple transmission-line model; but the accuracy of the improved transmission-line model is comparable to those of other more complicated methods[11].

Fig. 1.1(a) Microstrip Line  Fig. 1.1(b) Electric Field Line
Improved transmission-line models include substrate and conductor losses, aperture coupling, reactive effects, and the mutual coupling between the radiating apertures. The concept of the transmission-line model can be applied to any microstrip antenna configuration for which separation of variables is possible. Surface waves are not taken into account in the transmission-line model, which limits its use to thick and low substrate permittivity[12].

![Diagram of Radiating Slots, Patch, and Ground Plane]

**Fig. 1.2 Top and Side View of Rectangular Microstrip Antenna**

### 1.1.2 Cavity Model

Transmission line model 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 [13-21].
microstrip patch antennas being narrow-band resonant antennas can be treated as lossy cavity. Therefore, cavity model becomes a natural choice to analyze the patch antennas. This model is suitable for regular geometries for which the Helmholtz equation possesses an analytical solution, such as disks, rings, rectangles, triangles, and ellipses.

![Diagram of a microstrip antenna](image.png)

**Fig. 1.3 Charge Distributions and Current Density on a Microstrip Antenna**

When the microstrip patch is provided with power, the charge distribution occurs on the upper and lower surfaces of the patch and on the ground plane. This charge distribution is controlled by two mechanisms namely attractive mechanism and a repulsive mechanism[22]. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. Whereas, the repulsive mechanism occurs between the like charges on the bottom surface of the patch, which causes pushing out of some charges from the bottom, to the top of the patch. As a result of
this charge movement, currents flow at the top and bottom surface of the patch.

The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current flows on the top surface of the patch. As the height to width ratio further decreases, the current on the top surface of the patch becomes negligible. This does not allow the creation of any tangential magnetic field components to the patch edges. Hence, the four side walls are modeled as perfectly magnetic conducting surfaces. This implies that the magnetic fields and the electric field distribution beneath the patch are not disturbed. However, in practice, a finite width to height ratio exists and this does not make the tangential magnetic fields to be completely zero, but they being very small, the side walls can be approximated to be perfectly magnetic conducting.

This model has limitation due to its applicability only in low frequencies or electrically thin substrates; this is because the formulation inherently does not account for losses due to radiation and surface waves rigorously.

1.1.3 Full Wave Method – Moment Method

The most popular method, that provides the full wave analysis for the microstrip patch antenna, is the moment method[23]. In
mathematical literature, Moment Method is known as Weighted residuals and can be applied to the solution of both differential and integral equations. The method owes its name to the process of taking moments by multiplying the function with an appropriate weighting function and integrating. In microstrip antenna analysis with this method, the surface currents are used to model the microstrip patch and the volume polarization currents are used to model the fields in the dielectric slab. It has been shown by Newman and Tulyathan[23] how an integral equation is obtained for these unknown currents and using the method of moments, these electric field integral equations are converted into matrix equations which can then be solved by various techniques of algebra to provide the result. In electromagnetic theory, the method became popular after the pioneering work done by R.F.Harrington in 1967. Since than it has been one of the most popular methods for solving the electromagnetic boundary value problem.

1.1.4 Finite Element Method (FEM) of Analysis

The basic concept of Finite Element Method (FEM) [24] lies in the fact that although the behavior of a function may be complex when viewed over a larger region, a simple approximation may suffice for a small sub region. The total region is divided into a number of non-overlapping sub-regions called finite elements. In two dimensions usually polygons like triangles or squares or combinations of triangles
and squares are used for approximating the total surface. Regardless of the shape of the elements, the field is approximated by a different expression over each element, but where the edges of adjoining elements overlap, the field representation must agree to maintain continuity of the field. The equations to be solved are usually stated in terms not of the field variables but in terms of an integral type function such as energy. The function is chosen such that the field solution makes the functional stationary.

Finite element method is employed in many software packages for design and evaluation of microwave circuit performance. Its precision depends on developing proper meshing for the structure under consideration. So it is important to develop a tool that can provide a good mesh.

1.1.5 Finite-Difference Time-Domain (FDTD) Method

The FDTD method of analysis of an electromagnetic problem is a volumetric computational method. The FDTD technique is a numerical method for the solution of electromagnetic field problems with large numerical but a low analytical expenses. Despite the large numerical expenses, it is believed to be one of the most efficient techniques, because it stores only the field distribution at one moment in memory instead of working with a very large equation system matrix. The field solution for each time instant is then determined from
Maxwell's equations and is calculated using a time stepping procedure based on the finite difference formulation of Maxwell's equations in space and time[25-28]. In this method, Maxwell's equations are discretized in space and time over a finite volume, and the derivatives are approximated by finite differences. By appropriately selecting the points at which the various field components are to be evaluated, the resulting set of finite-difference equations can then be solved, and a solution that satisfies the boundary conditions can be obtained[29]. The method can efficiently be implemented on vector or on parallel computers. Sufficiently accurate results can be obtained by using a single precision floating point expression requiring only four bytes. FDTD method has been used for microstrip antenna analysis. Details of implementation reported by various authors differ in respect of excitation treatment, boundary conditions and post processing of results to obtain frequency parameters of interest[25-30]. The EM field in the space, which has to be analyzed, can be excited in different ways. A transient analysis, where pulse in space and time, e.g., in the form of a Gaussian pulse, is excited inside the circuit or component, is mostly used for the analysis of the microstrip antenna.

1.2 Motivation

In the era of 3G and upcoming 4G and 5G wireless applications, the demands are for miniaturized, high directional, high gain and
flexible conformal microstrip patch antenna. The microstrip antenna analysis performed by traditional methods are either less accurate or, computationally expensive. Therefore, design of microstrip antenna by such field analysis techniques is a difficult task for the researcher or engineers. At the same time, the bio-inspired soft-computing techniques like, Genetic Algorithm (GA), Particle swarm Optimization (PSO) and Artificial Neural Networks (ANN) etc. have received much interest in all areas of research [31-39]. Their extensive application to electromagnetic problem is yet to be achieved. The body centric communication demands for antennas with size reduction and with high efficiency. To design such antennas there is a tremendous demand on development of accurate computational tools. Looking into the needs of antenna and development of computationally efficient tool, the thesis is planned to address these issues.

1.3 Dissertation Overview

This dissertation consists of seven chapters. The first chapter is an introduction. It describes an overall outline of the thesis. Firstly it describes Microstrip Antenna and various analytical methods used for analysis. Then it explains about Genetic Algorithm and Artificial Neural Networks. A brief introduction to the combination of Genetic Algorithm and Artificial Neural Networks and its problem is also outlined. Further, a brief introduction to Finite Difference Time Domain technique for
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microstrip antenna analysis, is presented to build the background of the thesis. The objectives and methodologies are also presented.

Chapter two includes literature review of Genetic Algorithm and Artificial Neural Networks. It gives basic concept of Genetic Algorithm and Continuous Genetic Algorithm. It also describes different types of crossover. Advantages and care to be taken while implementing GA. It also outlines artificial neural networks and algorithms more specifically error back propagation.

Chapter three describes application of Genetic Algorithm on Microstrip Antenna designing as proposed by the candidate[40]. This chapter presents how the accuracy of the designing of Microstrip antenna can be improved using GA. The developed algorithm is used for designing rectangular, circular and triangular Microstrip antenna. The results found are validated by IE3D software of the Zealand Inc., USA and with the experimental results. The outcomes have been published for the benefit of the research community.

Chapter four starts with an introduction to Artificial Neural Networks. A tunnel-based Artificial Neural Networks is proposed to overcome the local minima. This is used to find out the radiation pattern of rectangular Microstrip antenna [41]. Proper selection of fitness function of genetic Algorithm is one of the major limitations of
GA. Hence, ANN is efficiently used to overcome such problems. A trained ANN is used as fitness function of GA which has been applied to design Microstrip antenna[42].

Chapter five shows how GA can be combined with ANN for weight optimization. Firstly Genetic Algorithm is used to fix the initial weight set of ANN and result is analyzed[43]. It is seen that 45% of computational time has been reduced with better accuracy. Then continuous/real valued crossover is replaced by introducing knowledge-based continuous Genetic Algorithm for training Artificial Neural Networks efficiently. The proposed technique is used to design Microstrip antenna[44]. Taking different steepness of activation for different neuron the problem of competing convention is taken care of while training Artificial Neural Networks using Genetic Algorithm. Here higher accuracy is achieved with 34% of computational time reduction. This technique is used to calculate resonant frequency of rectangular Microstrip antenna on thick substrate[45]. Finally, various parameters of Artificial Neural Networks are optimized by Genetic Algorithm. In this method, the man-time required to select the ANN parameters has been reduced considerably. Further, accuracy is improved by 30%. The proposed algorithm is applied to calculate resonant frequency of tunable single shorting post rectangular patch antenna[46].
Finite Difference Time Domain Technique and its use in analysis of microstrip antenna is described in chapter six. The presently used FDTD algorithm takes long computational time for simulation of high Q passive structure. In this thesis, the temporal neural networks is introduced which is then applied with FDTD technique, and is named as NFDTD[42]. Further to improve the time efficiency and accuracy using the approach of soft fusion, GA coupled ANN is incorporated with FDTD to develop GA-ANN-FDTD. The proposed technique is applied for the calculation of input impedance of rectangular patch antenna[47].

The conclusion and future scopes are presented in chapter seven.

1.4 Need for GA and ANN

Genetic Algorithm is a global search technique[31-33]. It is parallel in nature, i.e., the search is population to population but not point to point. It operates on encoded parameter instead of the parameters itself. Thus, non-differentiable functions as well as functions with multiple local optima represent classes of problems to which genetic algorithms can be applied[48,49]. On the other hand, Artificial Neural Networks is a mathematical model that learns from experience(training) and applies its knowledge for new unknown situations[50-52]. In the field of electromagnetics, there are various
problems, where it is required to optimize many parameters simultaneously. These problems are efficiently handled by using Genetic Algorithm. There are cases such as body centric devices, hand held devices etc., where it is very difficult to define the problem mathematically. In such cases, we take help of bio-inspired computing.

1.5 Connection Weight Determination

GAs are used to find a set of connection weights. The fitness of the network is determined solely by minimizing error. However, sometimes GA is used to select a suitable initial set of weights, that is, a set of weights which leads to a successful ANN after training with some standard training routines. In this case, the training time plays an important role[43-45,53].

1.6 Network Architecture Design

The network architecture is of great importance for the success of an ANN. For some problems, a big network is unavoidable, while for others smaller networks are more suitable. The space of all possible networks is infinite, and as yet there is little or no theory about what architecture works well for what problem. This makes GAs a viable tool to search for a better ANN solution.
1.7 Problems in Training of ANN by Means of GA

When the length of the chromosome is small, the ANN with GA approach works well. When the length of chromosome increases, a problem arises which is called, *The Problem of Competing Conventions*, or, permutation problem[53-55,56]. They are of two types:

**Hidden Node Redundancy:** A neuron sums the weighted inputs and applies an odd activation function to the sum to produce the output values. The output of the total network doesn’t change if the signs of all the incoming and outgoing weights are flipped. Since for every node in the ANN there are two possibilities, for the ANN as a whole, if there are \( n \) hidden nodes, there are \( 2^n \) different combinations.

(Two different but functionally equivalent neurons)

![Diagram](image)

Fig. 1.4 Hidden Node Redundancy (In case of an Odd Function)
**Hidden Layer Redundancy:** If a hidden neuron, with all its incoming and outgoing connections, is exchanged with another neuron with all its incoming and outgoing connections, we have a different structural representation of ANN, but functionally the ANN remains exactly the same. In a network with \( n \) hidden neurons, there are \( n! \) different combinations of these hidden nodes.

(Two different but functionally equivalent neurons)

![Diagram](image.png)

**Figure. 1.5 Hidden Layer Redundancy**

Since these two transformations are independent of each other, for a network with \( n \) hidden nodes, there are \( 2^n \times n! \) functionally equivalent but structurally different representations, if the activation function is odd, and otherwise \( n! \) different representations.

### 1.8 Competing Convention as a Big Problem

First, its existence dramatically increases the size of the solution space. That means, it takes a lot more time to converge to an
acceptable solution. Secondly, it almost completely destroys the usefulness of the crossover operator which is the most important operator in GA.

For instance, suppose that each character in the string codes one hidden node, and the string “abcdef” codes the fittest possible ANN. In the population are the strings “abcdeg” and “hbcdef”. If we cross these two strings, we might get the desired ANN. However, the second string may reside in the population as, for example, “fedcbh”. Crossing may now leave us with something like the strings “abccbh” and “feddeg”, which may not fit at all.

1.9 Handling the Problem of Competing Convention

It may be noted that some researches ignore the problem of competing conventions, and simply use the crossover operator. Ultimately, the performance reduces. However, there are some ways to overcome this problem[53] which are listed below.

i. Genetic Hill-climbing: To deal with hidden layer redundancy, many researchers have just left the crossover operator, and evolve ANNs with reproduction and mutation only. The GA process then becomes a kind of random. This is sometimes called Genetic Hill-climbing.
ii. Another simple way of dealing with the problem of hidden layer redundancy is using small populations. However, crossover is of no use any more, and the process is evolved with big mutation rate, strengthening the hill-climbing features.

iii. Restrictive Mating: Some literatures only use the crossover operator if the parents are not too different. This is sometimes called Restrictive Mating.

iv. Rearranging the Hidden Nodes in the Parent Individuals: It can also be handled by rearranging the hidden nodes in the parent individuals to place functionally equivalent hidden nodes in the same positions on both parent chromosomes.

Rearranging the hidden nodes seems to be the most effective. Since, it leaves all the aspects of GAs intact and is relatively easy to analyze and understand. The reason it is not always used is that it depends on the theory behind the determination of equivalent nodes of ANNs, how difficult the method is to implement and how much time it will cost. Most methods are very time consuming and difficult to implement. Montana and Davis[57] have also designed two techniques independently giving good results for small networks. But, they have also ignored the problem of compete conventions.
1.10 Finite Difference Time Domain Technique

In this section Yee’s FDTD scheme[25-30] in brief is discussed to implement for patch antenna. The FDTD update scheme is based on two spatial and temporal dependent equations. In a linear, isotropic, non-dispersive dielectrics, and non magnetic medium the time depended Maxwell’s equations are

\[
\frac{\partial \vec{E}}{\partial t} = \frac{1}{\varepsilon} \nabla \vec{H} \tag{1.1}
\]

\[
\frac{\partial \vec{H}}{\partial t} = -\frac{1}{\mu} \nabla \vec{E} \tag{1.2}
\]

where,

\( E \) - Electric field intensity

\( H \) - Magnetic field intensity

\( \varepsilon \) - Permittivity of the medium

\( \mu \) - Permeability of the medium

Under Cartesian coordinate system, these can be further expanded as:

\[
\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon} \left( \frac{\partial E_y}{\partial y} - \frac{\partial E_z}{\partial z} \right)
\]

\[
\frac{\partial H_y}{\partial t} = -\frac{1}{\mu} \left( \frac{\partial E_z}{\partial z} - \frac{\partial E_x}{\partial x} \right)
\]

\[
\frac{\partial H_z}{\partial t} = -\frac{1}{\mu} \left( \frac{\partial E_x}{\partial x} - \frac{\partial E_y}{\partial y} \right)
\]

\[
\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon} \left( \frac{\partial H_y}{\partial y} - \frac{\partial H_z}{\partial z} \right)
\]
\[
\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon} \left( \frac{\partial H_y}{\partial z} - \frac{\partial H_z}{\partial x} \right)
\]

\[
\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon} \left( \frac{\partial H_z}{\partial x} - \frac{\partial H_x}{\partial y} \right)
\]

\[(1.3)\]

The 2\textsuperscript{nd} order accurate central difference scheme as proposed by Yee is given by \[29,30\]

\[
\frac{\partial u}{\partial t} (i \Delta x, j \Delta y, k \Delta z, n \Delta t) = \frac{u^{n+1/2}_{i,j,k} - u^{n-1/2}_{i,j,k}}{\Delta t} \tag{1.4}
\]

Simplifying these equations by central difference scheme one will get,

\[
E_{x}^{n+1}(i, j, k) = E_{x}^{n}(i, j, k) + \frac{\Delta t}{\varepsilon} \left[ \frac{H_{x}^{n+1/2}(i, j, k + 1) - H_{x}^{n+1/2}(i, j, k)}{\Delta y} - \frac{H_{y}^{n+1/2}(i, j, k + 1) - H_{y}^{n+1/2}(i, j, k)}{\Delta z} \right]
\]

\[
E_{y}^{n+1}(i, j, k) = E_{y}^{n}(i, j, k) + \frac{\Delta t}{\varepsilon} \left[ \frac{H_{y}^{n+1/2}(i, j, k + 1) - H_{y}^{n+1/2}(i, j, k)}{\Delta z} - \frac{H_{z}^{n+1/2}(i + 1, j, k) - H_{z}^{n+1/2}(i, j, k)}{\Delta x} \right]
\]

\[
E_{z}^{n+1}(i, j, k) = E_{z}^{n}(i, j, k) + \frac{\Delta t}{\varepsilon} \left[ \frac{H_{z}^{n+1/2}(i + 1, j, k) - H_{z}^{n+1/2}(i, j, k)}{\Delta x} - \frac{H_{x}^{n+1/2}(i, j + 1, k) - H_{x}^{n+1/2}(i, j, k)}{\Delta y} \right]
\]

\[
H_{x}^{n+1/2}(i, j, k) = H_{x}^{n-1/2}(i, j, k) - \frac{\Delta t}{\mu} \left[ \frac{E_{x}^{n}(i, j, k) - E_{x}^{n}(i, j - 1, k)}{\Delta y} - \frac{E_{x}^{n}(i, j, k) - E_{x}^{n}(i, j, k - 1)}{\Delta z} \right]
\]

\[
H_{y}^{n+1/2}(i, j, k) = H_{y}^{n-1/2}(i, j, k) - \frac{\Delta t}{\mu} \left[ \frac{E_{y}^{n}(i, j, k) - E_{y}^{n}(i, j + 1, k)}{\Delta y} - \frac{E_{y}^{n}(i, j, k) - E_{y}^{n}(i, j, k - 1)}{\Delta z} \right]
\]
\[
\frac{\Delta t}{\mu} \left[ \frac{E_x^*(i, j, k) - E_x^*(i, j, k - 1)}{\Delta z} - \frac{E_x^*(i, j, k) - E_x^*(i - 1, j, k)}{\Delta x} \right] = H_z^{\text{en}}(i, j, k) = H_z^{\text{no}}(i, j, k) - \\
\frac{\Delta t}{\mu} \left[ \frac{E_y^*(i, j, k) - E_y^*(i - 1, j, k)}{\Delta x} - \frac{E_y^*(i, j, k) - E_y^*(i, j - 1, k)}{\Delta y} \right] \tag{1.5}
\]

The numerical algorithm for Maxwell's curl equations as defined by above equations requires that the time increment \( \Delta t \) have a specific bound relative to the spatial discretization \( \Delta x, \Delta y, \) and \( \Delta z \) [25]. For a linear, isotropic, non-dispersive and homogeneous dielectric with permittivity \( (\varepsilon) \) and permeability \( (\mu) \) the time increment has to obey the following bound, known as Courant-Friedrichs-Lewy (CFL) Stability Criterion and is expressed as

\[
\Delta t \leq \frac{1}{\sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}}} \tag{1.6}
\]

The structure and surrounding space are decomposed in parallelepipeds called elementary cells. The six components of the electromagnetic field are determined in each cell as shown in figure 1.6.
Due to finite capability of the computer used to implement the finite-difference equations, the mesh must be limited in the x, y and z directions. The difference equations cannot be used to evaluate the field components tangential to the outer boundaries since they would require the values of the field components outside of the mesh. One of the six mesh boundaries is a ground plane and its tangential fields are forced to be zero. Tangential electric field components on the other five walls must be specified in such a way that outgoing fields are not reflected using the absorbing boundary condition[58-62]. For the structures considered in this work, the pulses on the microstrip lines
will be normally incident to the mesh walls. Mur first order boundary condition[56] is applied at the boundary walls.

A raised cosine pulse is used at the feed point. At the feed gap the source is associated with an internal resistance[63] as shown in figure 1.7.

\[ I_s^{n-1/2} = (H_x^{n-1/2}(i_s, j_s, k_s - 1, k_s) - H_x^{n-1/2}(i_s, j_s, k_s))\Delta x \]
\[ (H_y^{n-1/2}(i_s, j_s, k_s) - H_y^{n-1/2}(i_s - 1, j_s, k_s))\Delta y \]

(1.7)

The field at the source is given by

\[ E_s^n(i_s, j_s, k_s) = V_s(n\Delta t)/\Delta Z + I_s^{n-1/2}R_s/\Delta z \]

(1.8)

The current at the feed point is calculated by integrating the magnetic field around the feed location. Which is given by

\[ I = \int H \, dl \]

(1.9)

and voltage at the feed location is given by

\[ V = -\int E \, dl \]

(1.10)
Finally the current and voltage are transformed to the Fourier domain.

The input impedance of the antennas is obtained from

\[ Z_{in} = \frac{V(f)}{I(f)} - R_s \]  \hspace{1cm} (1.11)

The implementation of FDTD algorithm is as shown in figure 1.8.

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**Fig. 1.8 Basic FDTD Algorithm**
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