CHAPTER - 1

Introduction
1.1 BACKGROUND

Observations of wind velocity profiles are very important for studying meteorological phenomena and weather forecasting. Atmospheric radar (wind profiler) is one of the most suitable remote sensing instruments for observing height profiles of three components of wind velocity vector, including the vertical velocity, height resolutions without influence of weather conditions.

Propagation of radar signals through the atmosphere is strongly dependent on local meteorological conditions, especially in the atmospheric boundary layer. The wind profiling radar uses naturally occurring fluctuations in the radio refractive index and precipitation as targets. Due to their small aperture, Ultra High Frequency (UHF) profilers operating around 900-1300 MHz are most suitable for measuring the wind velocities in the boundary layer and lower troposphere regions. Unlike the Very High Frequency (VHF) wind profiling radars, UHF radars are very sensitive for hydrometeors due to the small wavelength. Therefore these profilers are very much useful in studying convection, precipitation etc. UHF radar is a potential tool to carry out research studies such as Atmospheric Boundary layer (ABL) Dynamics (Winds, Turbulence structure), Seasonal and Inter-annual variations, Interaction between the ABL and the free troposphere, Precipitating systems, Bright and Characterization, Rain/Cloud drop size distribution etc. It is also useful in the operational mountain meteorology and civil aviation and identification of Atmospheric ducts. It also acts as a supplementary tool to large VHF Mesosphere Stratosphere and Troposphere (MST) radars by providing the atmospheric data in 0-5 km height range.

Earth’s atmosphere parameter measurement errors are highly dependent upon the instruments used for measuring it. The parameters of primary interest are temperature, pressure, humidity, precipitation and wind. Meteorological instruments have been refined over the years and routine surface measurements of these parameters have been made throughout the world since the nineteenth century. However, obtaining a systematic look at the space and time variability of the atmosphere as a function of height above the ground was not there until this century. Significant advances in this area were made some 50 years ago with the development of Radiosonde, a device carried aloft
by a balloon to measure temperature, pressure, humidity and transmit these data back to a
ground station. By tracking the motion of the balloon, the winds aloft could also be
determined. The Radiosonde has become the standard instrument for upper-air
instruments and today approximately 800 stations around the world release them on a
regular basis—usually every 12 hours.

Although measurements every 12 hours at these locations may be enough to
define the large-scale (synoptic) weather patterns, this is not sufficient to define the
significant smaller-scale weather events. Advances in our understanding of the weather
are dependent upon obtaining measurements with a higher resolution in both time and
space. Many other applications also require more frequent and more closely spaced
upper-air measurements. Even though Radiosonde are inexpensive, the relatively high
cost of maintaining balloon launching and tracking facilities has precluded more
extensive use.

Development of remote sensing technology offers a solution to this problem. In
particular, it is now possible to measure vertical profiles of the wind on a nearly
continuous basis, with accuracy better than that normally obtained with most balloons,
and more economically. These revolutionary instruments are known as wind profiling
radars. They are suitable as research tools in assisting scientists in a wide spectrum of
research interests, or as operational systems helping to bring practical benefits to users in
a variety of applications.

Although the initial applications of radar were for detecting solid objects,
such as airplanes, it was soon discovered that radar can also detect hydrometeors in
the atmosphere, principally those large enough to precipitate. Conventional Doppler
weather radars, which are designed to detect hydrometeor, are not sensitive enough
to detect the clear air, except under unusual conditions. On occasion, isolated
turbulent layers can be seen with these radars. A few wind measurements in these layers
were made during the same period and wind profilers were being developed.
The development of modern wind profiler is an outgrowth of research work done with
radars designed to probe the ionosphere, where longer wavelengths and
extreme sensitivity were required. During the later half of the 1960s, techniques
were developed to measure radial velocities of the ions and electrons in the
ionosphere, using the Doppler principle. These techniques were later used to examine the atmosphere below the ionosphere. The first wind soundings of the clear stratosphere were made by ionospheric physicists using ionospheric research radar at Jicamarca, Peru.

The success of Woodman and Guillen in obtaining strong continuous echoes between 10 and 35 km altitude inspired the use of other ionospheric radars to probe the troposphere and stratosphere. The real drive to make wind profilers practical for routine meteorological application came from the Wave Propagation laboratory of National Oceanic and Atmospheric Administration’s (NOAA) in the US during the early 1980s. The Colorado wind-profiling network, built under NOAA, had one UHF and four VHF radars. This network of systems, which has been followed by other countries, has provided important insight into the optimal design details for an operational network.

Since UHF wind profiling radar has good height resolution and allows coverage down to about 100 m above the ground, it can be used in a number of experimental and operational applications. To date over 100 UHF profilers have been produced by research and commercial groups for applications ranging from air quality studies to climate monitoring. Research applications include studies of low-level transport of water vapor, boundary layer convergence, frontal passages, low altitude turbulence, Global climate change studies, and vertical profiles of precipitation. Operational uses include air pollution prediction, wind shear monitoring, temperature profiling in the Radio Acoustic Sounding System (RASS) mode, Aviation operations, Mesoscale meteorological forecasting, Defense operations, Forest fire management, Weather modification and Offshore, Shipboard, and Airborne platforms. Since, these types of radars are very sensitive to heavy clouds and rain; they can be used to monitor the height of the melting layer and the vertical extent of hydrometeors. These small radars also provide temperature profiles up to 1-2 km when operated with an acoustic source in the (RASS) mode.

Several UHF radars are being operated across the globe either as research tools or as a part of wind profiler networks for operational meteorology. Atmospheric radars originally developed in 1970s for the research of mesosphere
and stratosphere wind fields since 1990s as demonstrated by the Wind Profiler Demonstration Network. In Japan, more than ten profilers including the Middle and Upper (MU) atmosphere radar of Kyoto University have been operated for research use. Through the research and evaluation of profiler’s data on the Numerical Weather Prediction (NWP) modes, Japan Meteorological Agency (JMA) established the operational Wind profiler Network and Data Acquisition System (WINDAS) for the enhancement of capability to watch and predict severe weather in Japan. The network consists of forty 1.3 GHz wind profiling radars which are located across Japan.

The objectives of the proposed UHF wind profiling radar are multi-fold. The present UHF radar at National Atmospheric Research Laboratory (NARL) was installed by Central Research Laboratory (CRL), Japan under the Indo-Japanese collaboration Program in the year 1997 as mentioned above. The system is getting aged and has many operational difficulties. As the collaboration period is over, CRL expressed inability to render operational and maintenance support. NARL has replaced the controlling and data processing subsystems to make the system operational. The RF/IF and Antenna systems also are giving operational problems. In view of these operational problems, NARL wants to develop alternative wind profiling radar for continuing the research in the lower atmosphere.

1.2 MOTIVATION

The National Atmospheric Research Laboratory goal is to explore and develop methods for improving observation, detection and prediction of atmospheric phenomena. The centre is focused on developing a Ultra High Frequency (UHF) Wind Profiling Radar (WPR) as a systems technology to improve our ability to monitor the earth’s lower atmosphere. Improving today’s weather monitoring and forecasting requires an increase in the resolution coverage of observations in the lowest kilometers of the atmosphere. The WPRs operating at the frequency range of 900 – 1300 MHz i.e. L-band with those previous conditions in mind.

Current approaches to sampling the first three kilometers of atmosphere are physically limited in their ability to provide the required resolution and coverage. These radars are used to cover distances up to 14 km, introducing limitations due to
the earth's curvature. As the range increases away from the radar, the earth's surface curves away under the radar beam creating an inability to observe the atmosphere close to the earth's surface. In addition, as the radar range increases there is a corresponding degradation of the radar resolution. The radar beam spreads proportionally to the sine of the antennas beamwidth, causing long-range cross-resolution on to degrade. Finally, radar suffers from terrain blockage. Obstacles such as mountain ranges also block the radar beam preventing observation of events beyond the obstacle. A network of L-band WPRs located at closer range will overcome the issues mentioned above.

In India the developed radars are 53 MHz Mesosphere Stratosphere and Troposphere (MST) radar at Gadanki, near Tirupati, 400 MHz Stratosphere and Troposphere (ST) radar at Indian Institute of Tropical Meteorology (IITM), Pune and S-band Doppler Weather Radar at SHAR, Sriharikota. A UHF wind profiling radar is yet to be developed in India. In recent times the necessity of this system is felt by several research and operational agencies for civilian and strategic applications. The proposed system will be a potential tool to probe the lower part of the atmosphere, which is very much related to weather and climate.

The radar should meet the following scientific requirements:

- It should provide data from 100m range onward
- It should provide clear-air wind profiles at least up to 6000m and provide precipitation up to 10 – 14 km.
- Detect strong and light precipitation echoes and
- 3 – D Characterization of the atmospheric turbulence.

The above requirements demand conflicting requirements on system hardware. In present-day radar systems, the need for antennas of small size and high efficiency has generated much attention in the study of compact microstrip antennas. These antennas exhibit low profile and light weight properties as well as low cross polarization radiation in some designs.
To obtain the data from the lowest range (100m), a very small antenna array as employed by Vaisala Wind Profilers (8X8 size) or a spaced antenna system, which needs segmentation of the array into smaller 8X8 sections is needed. On the other hand a large array (24X24) and high power (2 kW) are required to cover the 6 km for clear-air and 10-14 km for precipitation height range as in the case of Japan’s WINDAS profilers. In the present system a large array is replaced with advanced array of 16X16 to meet the above requirements and at the same time keep the beam width as narrow as possible for correct interpretation of the data.

The antenna array consists of 256 elements arranged in a 16X16 square grid. The interest here is to design and develop a 16X16 planar array. This antenna will be a square microstrip antenna. Here scanning will be made electronically in both azimuth and elevation.

1.3 OBJECTIVES

An L-band radar is operating at NARL, Gadanki with the following scientific specifications of the proposed system are given below

Mode of operation : Doppler Beam Swinging Technique
Minimum Range : 100 m
Maximum range : 6 km (clear air)
          : 10-14 km (precipitation)
Range Resolution : 30 m upto 3 km
          : 100 m upto 6 km
Measured parameters : Moments and U, V, W
Time Resolution : 5 minutes per profile

The main objective of this research is to design and develop a planar array antenna operating at 1.28 GHz for the wind profiling radars that meets the specifications needed for clear-air and precipitation estimation. Each patch is co-
axial or probe feed to minimize unwanted radiation. Finally, the simulated results need to be validated by the construction and measuring of antenna using the National Atmospheric Research Laboratory facilities.

1.4 PROJECT DESCRIPTION

The co-axial or probe feed arrangement, the centre conductor of the co-axial connector is soldered to the patch. The main advantage of this feed is that it can be placed at any desired location inside the patch to match with its input impedance. The feed lies behind the radiating surface, and therefore does not itself contribute unwanted radiation. It is a very convenient method of feeding by means of a surface mounted co-axial connector attached to the microstrip ground plane for experimental purposes [1] – [4].

A probe feed planar antenna array will be design using a substrate with permittivity of 2.2 and a thickness of 125 mills (3.175 mm) for the patch antenna. A cable with an outer diameter of 2.6 mm and a conductor diameter of 0.51 mm will be used for the feed. The array will be design to achieve a side-lobe level of 13.5 dB and the beamwidth of 4.5°.

1.5 LITERATURE SURVEY

Literature survey in the areas of microstrip antennas, analysis techniques for rectangular/square microstrip antenna, feed techniques, microstrip arrays are presented in this section.

1.5.1 Microstrip Antennas

In high-performance aircraft, spacecraft, satellite and missile applications, where size, weight, cost, performance, ease of installation and aerodynamic profile are constraints, and low profile antennas may be required. Presently there are many other government and commercial applications such as mobile radio and wireless communications, which have similar specifications. To meet these requirements, microstrip antennas can be used.

The microstrip antenna dates back about 54 years to work in the U.S.A by Deschamps [5] and in France by Gutton and Baissinot [6].
Shortly thereafter, Lewin [7] investigated radiation from stripline discontinuities. Additional studies were undertaken in the late 1960’s by Kaloi, who studied basic rectangular and square configurations.

However, other than the original Deschamps report, work was not reported in the literature until the early 1970’s, when a conducting strip radiator separated from a ground plane by a dielectric substrate was described by Byron [8].

This half-wavelength wide and several wavelengths long strip was fed by coaxial connections at periodic intervals along both radiating edges and was used as an array for project camel. Shortly thereafter, a microstrip element and a new class of antennas using microstrips to form the feed networks and radiators was presented by Munson [9] and data on basic rectangular and circular microstrip patches were published by Howell [10].


Sanford [12] showed that the microstrip element could be used in conformal array designs for L-band communication.

Additional work on basic microstrip patch elements was reported by Garvin et al. [13], Howell [14], Weinschel [15], and Janes and Wilson [16].

The early work by Munson on the development of microstrip antennas for use as low-profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems and thereby gave birth to a new antenna industry.

Mathematical modeling of the basic microstrip radiator was initially carried out by the application of transmission line analogies to simple rectangular patches fed at the centre of a radiating wall [17] [18]. The radiation pattern of a circular patch was analyzed and measurements reported by Carver [19].

The first mathematical analysis of a wide variety of microstrip shapes was published by Lo et al. [20], who used the model-expansion technique to analyze rectangular, circular, semicircular and triangular patch shapes.
Similar comprehensive reports on advanced analysis techniques were published by Derneryd [18], [21], Shen and Long [22], and Carver and Coffey [23].

Waterman and Henry [24] described the terms stripline and microstripline. A stripline or triplate device is a sandwich of three parallel conducting layers separated by two thin dielectric substrates, the centre conductor of which is analogous to the centre conductor of a coaxial transmission line. If the centre conductor couples to a resonant slot cut orthogonally in the upper conductor, the device is said to be a stripline radiator. Howard W. Sams [25] presented a microstrip device in its simplest form consists of a sandwich of two parallel conducting layers separated by a single thin dielectric substrate. The lower conductor functions as a ground plane and the upper conductor may be a simple resonant rectangular or circular patch. Carver and Mink [26] discussed the typical patch design factors like the quality factor, bandwidth and efficiency. A survey of microstrip antenna elements is presented with emphasis on theoretical and practical design techniques.

Analysis Techniques for Microstrip Elements

The microstrip antenna generally has a two-dimensional radiating patch on a thin dielectric substrate and therefore may be categorized as a two-dimensional planar component for the purpose of analysis. Carver and Mink [26] summarized several theoretical analysis techniques, including transmission line and model expansion (Cavity) techniques as well as numerical methods such as the method of moments and finite element techniques. Practical procedures are given for both standard rectangular and circular patches as well as variations on those designs including circularly polarized microstrip patches. Edward H. Newman and Pravit Tulyathan [27] developed the method of moments is used to analyze microstrip antennas of rectangular and nonrectangular shape. Surface currents are used to model the microstrip patch and volume polarization currents for the dielectric slab. The method requires unusually precise computation of the impedance matrix but is capable of accurately predicting currents, impedance, and resonant frequency of the antenna.
Tatsuo Itoh and Wolfgang Menzel [28] investigated a method for analyzing characteristics of open microstrip disk structures. The method is based on the spectral domain immittance matrix approach, and all the wave phenomena associated with the structures are incorporated. The method provides a number of unique and convenient features both in analytical and numerical phases.

Bailey and Deshpande [29] introduced a problem of microstrip antenna covered by a dielectric is formulated in terms of coupled integro-differential equations with the current distribution on the microstrip patch as an unknown variable. Galerkin's method is used to solve for the unknown patch current. Using the present formulation the resonant frequency and bandwidth of a rectangular microstrip antenna are determined.

Girish Kumar and Guptha [30] described a method for increasing the bandwidth of microstrip patch antennas by incorporating two additional resonators which are gap-coupled to the radiating edges of a rectangular patch. A two dimensional analysis using Green's function and segmentation method is used for analyzing the proposed antenna configurations. A bandwidth as large as five times a single rectangular patch is obtained in S-band. Changes in the radiation pattern over this wide bandwidth are discussed.

Edward H. Newman and John E. Tehan [31] presented an analysis technique for a microstrip array. The array elements and mutual coupling between elements are analyzed by a Method of Moment (MoM) solution of the exact integral equation. The combination of the microstrip array elements, plus the microstrip transmission line feed network is analyzed using a generalized Thevenin's theorem. The method is applied to the specific problem of the series fed microstrip array.

David M. Sheen, Ali, Abouzahra and Kong [32] developed a direct three-dimensional finite-difference time-domain [FDTD] method is applied to the full-wave analysis of various microstrip structures. The method is shown to be an efficient tool for modeling complicated microstrip circuit components as well as microstrip antennas. From the time-domain results, the input impedance of a line-fed rectangular patch antenna and the frequency dependent scattering parameters of a low-pass filter and a branch line coupler are calculated.
Chao-FuWang, Feng Ling, Jian-Ming Jin [33] proposed a fast full-wave analysis technique that can be used to analyze the scattering and radiation from large finite arrays of microstrip antennas. The technique discretizes the mixed potential integral equation in the spatial domain by means of a full-wave discrete complex image method.

A finite element boundary integral method was developed by Sangster and Jacobs [34] to investigate the impedance properties of patch elements in an array environment, when the array is embedded in a conformal surface. The effect of mutual coupling between elements in such an array is included in the analysis.

Ning Yuan, Tat Soon Yeo, Xiao-Chun Nie and Le Wei Li [35] presented an accurate and efficient method that combines the precorrected Fast Fourier Transform (FFT) method and the discrete complex image method (DCIM) to characterize the scattering and radiation properties of arbitrarily shaped microstrip patch antennas. In this method, the mixed potential integral equation (MPIE) was discretized in the spatial domain by means of the discrete complex image method. The resultant system is solved iteratively using the generalized conjugate residual method (GCR). The precorrected-FET technique was proposed to speed up the matrix vector multiplication. The precorrected-FET eliminates the need to generate and store the usual square impedance matrix and thus leads to significant reduction in memory requirement and computational cost.

1.5.2 Feeding Techniques

The microstrip antenna can be excited directly either by a coaxial probe or by a microstrip line. It can also be excited indirectly using electromagnetic coupling or aperture coupling and a coplanar waveguide feed, in which case there is no direct metallic contact between the feed line and the patch [1] – [4]. Feeding technique influences the input impedance and characteristics of the antenna, and is an important design parameter.

Oltman and Huebner [36] described a new class of printed circuit radiator consisting of a microstrip dipole electromagnetically coupled to a microstrip feed line. Several configurations which differ in bandwidth, efficiency and construction
simplicity are presented. A geometry which has been found to be optimum for many
applications is noted. Radiation characteristics of both isolated elements and arrays
of elements are examined.

Using Richmond's reaction integral equation, an expression is derived for the
input impedance of microstrip patch antennas excited by either a microstripline or a
coaxial probe was introduced by Deshponde and Bailey [37]. The effects of the
finite substrate thickness, a dielectric protective cover and associated surface waves
are properly included by the use of the exact dyadic Green's function. Using the
present formulation the input impedance of a rectangular microstrip antenna is
determined.

Katehi and Alexopoulos [38] presented a generalized solution for a class of
printed circuit antennas excited by a strip transmission line. The strip transmission
line may be embedded inside or printed on the substrate.

Pozar [39] described a new technique for feeding printed antennas. A
microstrip antenna on one substrate is coupled to a microstrip line feed on another
parallel substrate through an aperture in the ground plane which separates the two
substrates. A simple theory explaining the coupling mechanism is presented, as well
as measurements of a prototype aperture-fed antenna.

Gronou and Wolff [40] presented a theoretical treatment and experimental
results on a resonant-slot coupled microstrip resonator with a dielectric overlay. The
resonator is coupled by a resonant slot in the ground plane to a microstrip feed line.
The return loss and radiation pattern of the antenna are presented.

Chung-Cytz Liu, Alexander Hessel and Jerry Shmoys [41] discussed the
performance trends of large phased arrays with probe fed microstrip patch elements.
In view of space constraints, they were limited primarily to single probe for
rectangular grid arrays with rectangular patch geometry.

Pozar and Targonski [42] described an aperture shape that gives significantly
improved coupling for an aperture coupled microstrip antenna. This aperture
consists of the usual rectangular slot, augmented with loading slots at each end,
which determined better input impedance than the resonant input impedance.
T. Hynh and K. F. Lee [43] proposed a coaxially fed single-layer single-patch wideband microstrip antenna in the form of a rectangular patch with a U-shaped slot. Measurements showed that this antenna can attain 10-40% impedance bandwidth without the need of adding parasitic patches in another layer or in the same layer.

Kin-Lu Wong and Jian-Yi Wu [44] described the design of a single feed small microstrip antenna with circular polarization (CP) radiation. This design is achieved by cutting slits in the square patch and by adjusting the lengths of the slits; the microstrip antenna can perform circular polarization radiation with a reduced patch size at a fixed operating frequency. This also provides a wide circular polarization bandwidth and relaxed fabrication tolerances.

Targonski, Waterhouse, and D. M. Pozar [45] presented a variation of the aperture-coupled stacked patch microstrip antenna which greatly enhances its bandwidth. Bandwidths of up to one octave have been achieved. The impedance behavior of this antenna is compared with that of other wide-band microstrip radiators. The effects of varying several key physical parameters of the antenna are investigated. Variations on the design such as incorporation of additional patches are also discussed.

Mak, Luk, Lee and Chow [46] proposed the L-shaped probe, to be an attractive feed for the thick microstrip antenna. A parametric study on the rectangular patch antenna is presented. It is found that the antenna attains 36% impedance bandwidth (SWR ≤ 2) as well as gain bandwidth and about 7 dBi average gain. A two-element array fed by L-probes is also proposed, it can substantially suppress the cross polarization of the proposed antenna.

A novel slotted rectangular microstrip antenna for dual-frequency operation was developed by Chen [47]. The microstrip antenna is fed by a single probe feed and has a η-shaped slot embedded close to the patch's radiating edge. The two operating frequencies have the same polarization planes and similar broadside radiation characteristics. By varying the lengths and the spacing of the two arms of the η-shaped slot, the proposed antenna can have a tunable frequency ratio ranging from about 1.12 to 1.64.
Al-Jibouri, Evans, Korolhiewicz, Lim, Sambell and Viasits [48] presented a cavity model used to analyze an aperture-fed nearly square circularly polarized patch antenna. The form of the aperture is that of a symmetric cross-slot that couples the excitation between a single microstrip feed line and the patch antenna. Using equivalent magnetic current sources at the slots, the model electric and magnetic fields under the patch are obtained, and hence analytical expressions for the patch admittances at the aperture are derived and used to obtain an equivalent circuit of the circular polarized antenna.

A prototype 1X4 microstrip array antenna for the IMT-0020 base station using +1-45° slanted polarization diversity is proposed to overcome the problems of space diversity. 'T' shaped aperture coupled feeds are used to obtain good isolation by Lee, Kwon and Choi [49] for a single radiating element, isolation of upto 50 dB between the two ports has been obtained.

Rao, Denidni, Sebak and Johnston [50] proposed a novel aperture coupled microstrip antenna. This structure uses a single substrate for achieving a low profile, good radiation efficiency and reduced back radiation. This structure can achieve high radiation efficiency, 25 dB front-to-back radiation ratio and 30 dB cross-polarization field levels below the corresponding co-polarization field level. This type of structures are important for mobile communication systems.

Chiu, Chan and Luk [51] presented a series of simulations and experimental investigations of slotted microstrip patch antennas with a folded patch feed. He also introduced the effects of varying the location of the feed and the shape of slot. All the investigated antennas are fed by a bandwidth enhanced feeding method: folded patch feed. The folded patch feed is an attractive tailor-mode feeding method for microstrip patch antennas, resulting in an impedance bandwidth of more than 50%. The folded patch feed has been applied to different shapes of slots and some of them profit with a wider impedance bandwidth over a rectangular U-slot shape.

1.5.3 Microstrip Arrays

One of the best features of microstrip antennas is the ease with which they can be formed into arrays, and a wide variety of series-fed, corporate fed, scanning and polarization-agile arrays have been designed using microstrip elements [2], [3], [52] and [53].
Microstrip patch antennas are inherently low-gain antennas and this fact partially offsets the disadvantages they offer in terms of cost and ease of fabrication. However, microstrip patch antennas are particularly well suited from a technological point of view to be grouped in large arrays to obtain high gain. Typically, the feed lines are integrated on the same substrate. The present work is concerned the actual arrays of microstrip patch antennas and how the numerical techniques presented can be applied to the study of arrays but not the feed network.

There are finite and infinite array techniques that can be used to study larger arrays without simply using a larger computer or more computer time. However, it should be noted that the simulation time could be low when the ground plane is infinite. For the finite ground plane, both the patch and the ground plane are divided into number of segments and hence the simulation time increases. In practice, the size of the ground plane is finite and it can be taken into account by numerical techniques.

Chung-Cytz Liu, Jerry Shmoys, Alexander Hessel, Jerome D. Hanfling and Joseph M. Usoff [54] demonstrated a numerical solution of plane wave reflection from an infinite planar rectangular microstrip-patch array on a grounded dielectric substrate and compared to phased array simulator measurements with a good correlation. In the theory, particular attention is paid to the edge condition and to the convergence of the matrix elements which was accelerated by the Poisson Summation Technique, as well as to the rate of convergence of the overall solution.

Pozar [55] analyzed finite phased arrays of rectangular microstrip patch antennas. Reflection coefficient magnitudes, element patterns and efficiency are calculated for various sized arrays on substrates of practical interest and are compared with previous infinite array solutions.

Levine, Shtrikman and Treves [56] presented a feeding technique for double-sided printed dipoles enabling the realization of flat arrays on foam-like substrates with bandwidths up to 25%. An experimental comparison with thin single-layer microstrip arrays shows that the available gains are equal, while the bandwidths for the double-sided dipole are much larger. He also proposed a modification of microstrip analysis and it provides useful design data for the double sided elements.
Aberle and Pozar [57] described an analysis of infinite arrays of rectangular microstrip patches with each element fed by one or two coaxial probes. The probe self-impedance and the rapidly varying patch current near the feed connection point are rigorously included in the analysis by using an attachment mode derived from the corresponding cavity model solution. Two-probe-fed patches are analyzed for both reduced cross-polarization and circular-polarization applications, and the effect of probe-to-probe coupling in the unit cell is determined. The theory generates results in excellent agreement with waveguide simulator measurements over a wide range of substrate dielectric constants and thicknesses for both one and two-probe-fed patches, overcoming the drawbacks of previous solutions that used an idealized probe feed model. Similar solutions can be developed for other types of patch antennas and arrays.

David M. Pozar [58] proposed the analysis of an infinite array of aperture coupled microstrip patch antennas; this type of element is well suited to integrated phased array applications, offering several advantages over other array configurations. The solution employs the spectral domain moment method approach, and combines features of a previous solution for infinite arrays of probe-fed patches and a reciprocity analysis of a single aperture coupled microstrip element. The theoretical analysis was described and data are presented for the active input impedance of several arrays.

David M. Pozar and Barry Kaufman [59] discussed and quantified the factors affecting the realizable sidelobe performance of microstrip arrays. These include excitation amplitude and phase accuracies, mutual coupling, diffraction effects, positioning errors and errors due to imperfect element matching and feed network isolation. Also, it shown those low-sidelobe microstrips arrays require a very light tolerance on the resonant frequencies of the elements, and the elimination of spurious radiation from the feed network; cross-pol and surface wave effects are also discussed.

Jian-Ming Jin and John L. Volakis [60] presented a hybrid numerical technique for a characterization of the scattering and radiation properties of microstrip patch antennas and arrays residing in a cavity recessed in a ground plane.
The technique combines the finite element and boundary integral methods to formulate a system for the solution of the fields at the aperture and those inside the cavity via the biconjugate gradient method in conjunction with the fast fourier transform (FFT). By virtue of the finite element method, the proposed technique is applicable to patch antennas and arrays residing on or embedded in a layered dielectric substrate and is also capable of treating various feed configurations and impedance loads. Several numerical results are presented demonstrating the validity, efficiency and capability of the technique.

Adrian S. King and Wallace J. Bow [61] proposed a full-wave solution to the problem of plane wave scattering by a finite array of rectangular microstrip patches printed on a grounded dielectric slab. The electric field integral equation is solved using the spectral domain Green’s function/moment method approach. Derivations for the elements of the impedance and voltage matrices are presented. An efficient massively parallel computer implementation of the moment method solution is described. Computed radar cross section (RCS) data for microstrip patch antenna arrays is presented as a function of incident signal frequency and angle of incidence.

James T. Aberle, David M. Pozar and John Manges [62] developed infinite phased arrays of probe-fed stacked rectangular and circular microstrip patches. A numerical model is described that is based on a rigorous Green’s function/Galerkin solution. In this solution, the connection of one or more vertical probe feeds to each patch is accurately modeled using a special attachment mode basis function, which is derived from the corresponding cavity model solution.

Sridhar Kanamaluru, Ming-yi Li and Kai [63] presented the analysis and design of aperture coupled microstrip patch antennas and arrays fed by an dielectric image line. A theory based on the cavity model of the microstrip patch antenna and the change in the model voltage of the image line at the aperture was developed to analyze the single element aperture coupled microstrip patch antenna. The theory developed was combined with the array theory to design linear traveling wave arrays at X-band and Ka-band frequencies. The required taper in the excitations of the individual patches of the array was achieved by varying the aperture dimensions.
Arun K. Bhattacharyya [64] described a numerical model to analyze multilayered microstrip infinite phased array antennas. The model is based on modular approach where each layer is considered as a module characterized by its generalized scattering matrix. The individual scattering matrices are combined in appropriate sequence to yield the overall scattering matrix and the impedance matrix of the structure.

Davis M. Pozar, Targonski and Syrigos [65] discussed the theoretical modeling and practical designs of millimeter wave reflect arrays using microstrip patch elements of variable size. A full-wave treatment of plane wave reflection from a uniform infinite of microstrip patches is described and used to generate the required patch design data and to calculate radiation patterns of the reflect array. The critical parameters of millimeter wave reflect array design, such as aperture efficiency, phase errors, losses and bandwidth are also discussed. Several reflect array feeding techniques are also described.

HERve legay and L. Shafai [66] proposed a novel technique for feeding microstrip antenna arrays. It consists of a microstrip feed network designed to operate in dual standing and traveling wave modes and provide uniform excitation to its elements with either mode. It, therefore, produces a uniform aperture distribution, regardless of the array element input impedances. The traveling wave propagates when radiating elements are matched, but resonant standing wave prevails if loads become mismatched. Since the feed network resonance does not alter the array excitation, it can be used in combination with the radiating patch resonance to broaden the impedance bandwidth. The physical reasons for such behaviors are explained and experimental verification are provided. The generalization of the concept to large arrays is also discussed.

Miguel A. Gonzalez de Aza, Jose A. Encinar, Juan Zapata and Manuel Lambea [67] presented a full-wave method to analyze probe-fed infinite phased arrays of arbitrarily shaped microstrip patches residing in a cavity. The method is based on a combination of the mode matching and finite-element methods (MM-FEM) and provides a rigorous characterization of the coaxial feed. The radiated field to the half space is expressed as a Floquet's harmonic expansion reducing the analysis to a single elementary cell of the periodic antenna. The unit cell is analyzed
as an open-ended succession of homogeneous waveguides of diverse cross sections. Each transition between waveguides is solved by a hybrid MM-FEM procedure to obtain its generalized scattering matrix (GSM). Finally, the GSM of the structure, which characterizes the array, is obtained from the individual GSM’s by a cascading process. The method is also extended to microstrip arrays by using the waveguide simulator model. Several prototypes, implemented and measured in waveguide simulator, have been analyzed to prove the validity and efficiency of the proposed method.

Guy A. E Vandenbosch, and Filip J. Denuynck [68] introduced a new expansion scheme to solve the integral equations describing the mutual coupling in microstrip arrays. The scheme is based on the fact that at larger distances the Green’s functions in the stratified dielectric medium of the antenna structure can be approximated using analytical expressions. This allows one to describe the waves propagating between the elements thus causing the mutual coupling with a small number of parameters.

Derek Gray, Jun Wei Lu and David V. Thiel [69] described a dual frequency circularly polarized electronically steerable microstrip patch antenna array suitable for land-mobile communications. Based on a four element yagi-uda patch antenna, the four antennas forming the array are located radially from a single square reflector patch on a double-sided printed circuit board.

Ming Li and Kai Chang [70] presented a novel low-cost beam-steering techniques using microstrip patch antenna arrays fed by dielectric image lines (DIL’s). Two approaches are designed and used. The first, DIL’s without plate, are used for feeding microstrip patch antenna arrays. Antenna array radiation beams are scanned when the operating sweeps. The second, a dielectric image line with a movable reflector plate (DILWRP), is developed. The beam direction of the antenna array is controlled and steered by changing the perturbation distance between DIL and movable reflector plate at a given operating frequency. Both types of patch antenna array structures are simple, low cost, easily fabricated, stable and reliable. Eight-element patch antenna arrays fed by DIL and DILWRP have been designed, fabricated and tested.
Marg, Schan and Jacob [71] studied the radiation characteristics of microstrip antennas consisting of two patch elements on small size substrates by means of an approximate solution technique. Special attention is paid to the shielding effect due to finite ground plane diffraction. Experimental and theoretical results show that the back radiation is influenced by the sidelobe level and can further be reduced when the antenna is boxed. For a correct radiation pattern computation these diffraction effects need to be included in the design of small array as well as in that of single element antennas.

Gao, Li, Yeo and Leong [72] presented the design and experiments of a novel dual linearly polarized (LP) microstrip antenna array with a high isolation and low-cross-polarization levels are presented. The theoretical analysis is based on the finite-difference time-domain method and the multiport network model. The multifeed technique and the diagonal feeding are combined to realize the dual-polarized antenna elements. A single antenna element is designed and the experimental results show a good isolation between two polarization ports. The dual linear polarization elements are sequentially rotated to form the microstrip antenna array. A four-element dual LP array is also designed at 6.6 GHz and measured. Both theoretical and experimental results are presented and compared.

Lau, Luk and Lee [73] proposed the design and measured results of a wideband antenna array of four U-slot rectangular patches. The U-slot patches are proximity coupled by a microstrip feed line terminating with novel n-shaped stubs. By using a foam layer of thickness t ~ 5.5 mm as the supporting substrate, an impedance bandwidth of 27% ranging from 3.4 GHz to 4.5 GHz is achieved.

Pozar and Targonski [74] described the design and testing of a prototype dual-band dual-polarized planar array operating at L- and X-bands. The primary objectives were to develop new antenna technology with dual-band and dual-polarization capability in a shared aperture, featuring low mass, high efficiency and limited beam scanning. The design of a prototype planar microstrip array of 2X2 L-band elements interleaved with an array of 12X16 X-band elements that meets these requirements is discussed in detail and measured results are presented. The array is modular in form and can easily be scaled to larger aperture sizes.
Paron, Rius and Mosig [75] discretized the application of integral equation methods based in the method of moments to solve large antenna arrays is difficult due to the fact that the computational requirements increase rapidly with the number of unknowns. This is critical when a frequency analysis of the antenna is required. The multilevel matrix decomposition algorithm (MLMDA) to carry out this purpose efficiently. As the MLMDA method is particularly well suited for the analysis of planar structures with any Green’s function, it is a very efficient approach for the frequency analysis of microstrip antenna arrays.

Abd EI-Raouf, Prakash, Yeo and Mittra [76] proposed a novel approach for analyzing microstrip patch antennas using the finite difference time domain (FDTD) technique. Specific attention is paid to the issue of modeling the coaxial feed line, using a voltage source with a lumped resistance type of internal impedance. The results of the simulation are found to be in close agreement with those derived by using Method of Moments (MOM). The analysis is then extended to the case of planar arrays of microstrip patch antennas.

Zeev Iluz, Shavit and Bauer [77] presented uniplanar compact electromagnetic bandgap (UC-EBG) substrate which has been proven to be an effective measure to reduce surface wave excitation in printed antenna geometries. The performance of a microstrip antenna phased array embedded in an UC-EBG substrate is investigated. The results show a reduction in mutual coupling between elements and provide a possible solution to the “blind spots” problem in phased array applications with printed elements. A novel and efficient UC-EBG array configuration is proposed.

Noh and Park [78] developed a microstrip patch array antenna for transmitting (Tx) and receiving (Rx) in the Ku band. The patch array antenna has horizontal polarization for the receiving band and vertical polarization for the transmitting band. The element of the patch array antenna was designed as a three-stacked structure consisting of one radiation patch and two parasitic patches for high gain and wide bandwidth characteristics. The unit elements were arranged in a 1X8 array using a mixture of series and parallel feeds. To verify the practicality of this antenna, a three-stacked patch array antenna was fabricated and its performance was measured.
The above observations on microstrip antenna analysis techniques for microstrip elements, feeding techniques, and microstrip arrays to a large extent, the development of microstrip antennas have been driven by systems requirements for antennas with low-profile, low weight, low-cost, easy integrability into arrays or with microwave integrated circuits or polarization diversity. In the present work a square shaped microstrip antenna with coaxial or probe feed is preferred and to analyze this antenna, the transmission line model is used. To improve the gain; an infinite ground plane planar square microstrip antennas are considered to get the specifications of wind profiling radars using Integrated Electromagnetic 3-Dimensional (IE3D) [79] and Advanced Design Systems (ADS) [80] software based on Method of Moments (MOM).

1.6 WORK ORGANIZATION

The thesis is organized into seven chapters. Chapter 1 is introductory in nature wherein the background, motivation, objectives and Project description for the present study is presented. The literature review for microstrip antennas and the outline of the thesis are specified.

The theory of microstrip antennas, different shapes, analysis techniques for microstrip antennas, feed techniques, square/rectangular microstrip antenna and planar arrays are described in Chapter 2.

Chapter 3 deals with the design of a microstrip antenna element and the analytical model for microstrip antenna analysis. The sensitivity analysis for a single microstrip antenna is also presented in this chapter.

Design and analysis of an array is discussed in Chapter 4 for 2X2, 4X4 and 8X8 with the element spacing of 0.73λ₀ (λ₀ free space wavelength). Chapter 5 describes the design and analysis of a 16X16 planar array to achieve the specifications of the system. Chapter 6 covers the fabrication and testing of the antenna.

Finally, the conclusions and recommendations for future work are presented in Chapter 7.