CHAPTER-1
INTRODUCTION

1.1 GENERAL

Small size, lightweight, low profile, broad bandwidth, and proper polarization are the fundamental requirements in antenna design for wireless communication systems. Microstrip antennas, for a long time, have been attractive choices for such applications. To reduce the size of the microstrip antenna, a large number of techniques have been proposed, such as using shorting post at strategic locations [77, 78], using high dielectric constant substrates and removing non-radiating edges [84]. Among these techniques, the use of shorting posts at the strategic locations reduces the size of the patch antenna effectively. But the shorting post disturbs the radiation characteristics, such as a shift in the pattern, high cross-polarisation levels, a dip in the E-plane pattern, and low radiation efficiency and consequently reduces the gain of the patch antenna. To overcome all these problems, and also to enhance the bandwidth, several techniques have been proposed [114, 115].

In this thesis, to improve the bandwidth, gain, radiation efficiency, radiation patterns and the cross-polarisation levels of the shorted microstrip antenna, electromagnetically coupled shorted microstrip antenna configurations are presented [118-121]. These new structures offer a significant reduction in the cross-polarisation levels of a shorted patch and at the same time are found to exhibit a large impedance bandwidth with a higher gain as well as radiation efficiency. A common technique of enhancing the bandwidth of parasitically coupling another microstrip radiator to the driven element of the shorted patch is employed. In lieu of a co-planar version of parasitic coupling, a concentric vertically stacked electromagnetically coupled geometry is utilised. Thus the new configuration presented here consists of ring structures as parasitic radiator, stacked and EM coupled to a concentric shorted driven patches. The bottom driven patch element with a shorting post reduces the size of the antenna and also excites the dominant mode on the stacked radiating structures, thereby utilizing the resonance of both radiators to significantly improve the bandwidth. These geometries are compatible in size as required for mobile communication handsets.
1.2 HISTORICAL REVIEW

The concept of microstrip radiator was first proposed by Deschamps [15] in 1950s. However, serious attention was given to this element only in the early 1970s by Howell [19] and Munson[29], when they developed practical antennas. Since then extensive research and development of microstrip antennas and arrays have led to new configurations and applications.

Various types and shapes of microstrip antennas that have been developed are printed dipoles, patches of various geometries, like the rectangular, circular, elliptical, annular ring, and pentagonal, travelling wave lines, and curved lines such as the spiral, or circular sector. Perturbing slots and tabs have been used to produce circular polarisation. Parasitic elements, linear and non-linear loading, and multilayer configurations have also been used to increase bandwidth ([4], [9], [13], [17], [22], [23]).

For the theoretical analysis, a rectangular microstrip antenna has been modeled as two parallel radiating slots connected by a low characteristics impedance transmission line ([13], [29]). Each slot radiates a field similar to a magnetic dipole [10] and the radiation pattern of the patch is obtained by employing the principle of multiplication of patterns [14]. This model is found to be more suitable for patches of rectangular shapes, although Bhattacharya and Garg [6] have attempted to extend the transmission line model for patches of arbitrary geometries.

Lo et al. [26] have used a modal expansion technique to analyse a wide variety of patch shapes. In this technique, the microstrip patch is viewed as a thin TM-mode cavity bounded by magnetic walls along the edge and electric walls at the top and bottom. The field between the patch and the ground plane is expanded in terms of a series of normal modes of the cavity. The effect of radiation and other losses is accounted for either by artificially increasing the substrate loss tangent or by imposing the impedance boundary condition at the walls [8]. This results in a more accurate formulation for input impedance, resonant frequency and radiation patterns although at a modest increase in mathematical complexity. Derneyard [59] has used this method to analyse the circular disk antenna by treating it as a cylindrical cavity with magnetic walls. Richard et al.[39] have improved the cavity model to incorporate multiple feeds and have evaluated the input impedance of rectangular and circular microstrip antennas for various feed point locations. Cavity model, which is the simplest one used for the calculating the radiation characteristics of circular
microstrip antenna, has been rigorously treated by many authors like Long et al. ([66],[67]), Watkins[68], and Wood[69].

Yano and Ishimaru [70] have employed the Green's function technique and have evaluated the input impedance of circular disk microstrip antenna. Shen [41] has presented a theoretical analysis of an elliptical microstrip antenna in which the far fields are expressed in terms of Mathieu functions. He has shown that circular polarisation over a narrow frequency band may be achieved with single feed point. Fonseca et al.[60] have presented on the efficiency and directivity of microstrip disk antennas by studying the excitation of surface wave modes.

Most of the above methods assume that the substrate electrical thickness is small. Chew and Kong [55] have presented a rigorous analysis of a circular disk antenna on a thick dielectric substrate, using Vector Hankel transforms. The problem has been formulated in terms of vector dual integral equations from which the unknown current on the patch may be obtained. It is also shown that this method of solution reduces to the modal theory approach for thin dielectric substrates. Characteristics of circular patch on thick substrates have also been studied by Bhattacharya [52].

Most rigorous spectral domain approaches employing Galerkins method and current expansions based on TM and TE modes of the magnetic wall cavity or basis functions accounting for the edge effects, have been used to analyse rectangular ([32],[33],[34]), circular ([53],[54]), annular ring [2] and elliptic [18] geometries.

To account for microstrip patches of arbitrary shape, several numerical techniques, including method of moments and the finite element technique have been used to obtain unknown surface currents or cavity field. Newman ([30],[31]) has employed the method of moments to analyse the thin substrate antennas embedded in a dielectric slab. The moment method in the space domain using piecewise sinusoidal basis function, has been employed by Uznuoglu [43] to analyse printed dipoles. Mosig and Gardiol ([27],[28]) have solved the two dimensional electric field integral equation for microstrip antenna structure, by the moment method using the subsectional basis functions and the point matching technique. This method may also be extended to microstrip patches of arbitrary shapes. Willies and Sengupta [44] have applied the Gradient Fast Fourier Transform (CGFFT) technique to solve the integral equations in the spectral domain which are derived for the total patch current using Dyadic Green's functions method. This method is novel in the sense that it
distinguishes between the currents on the top and bottom surfaces of the patch. Bhattacharya et al. [51] have used spectral domain analysis for finding out wall admittance of circular and annular microstrip patches, and to study the effect of surface waves.

Deshpande and Bailley [16] have derived an expression for the input impedance of microstrip antennas excited by either microstrip transmission line or a coaxial probe using Richmond’s reaction integral equation and the dyadic Green’s function for the layered media. Davidovitz and Lo [58] have calculated the input impedance of a coaxial fed circular microstrip antenna by expanding the field in terms of the modes of an eccentric annular wave guide and solving for the coaxial aperture field due to an incident TEM wave. All losses including radiation have been lumped into an effective loss tangent.

SHORTED MICROSTRIP ANTENNA

Owing to the recent developments in the miniaturization of mobile communication equipment, the design of small antennas (Compact) has received much attention. Many of the research workers have applied the different techniques to reduce the size of the microstrip antennas, such as using the shorting post at strategic location, high dielectric constant substrate, by removing the non-radiating edges and by putting slots on the radiating elements.

In 1994, M. Sanad has studied the effect of shorting posts on the resonant frequency of the rectangular microstrip antenna and it has been concluded that by using the very less number of shorting posts (1 to 3), instead of a complete shorting of the one of the radiating edges, reduces the size of the antenna to a quarter wavelength. The shorted microstrip antenna has been analysed by modeling the shorted posts as short pieces of a transmission line [77].

Waterhoues presented single shorted circular microstrip antenna [78]. By using the fullwave analysis the input impedance characteristics have been studied. The variation of the resonant frequency of the triangular patch with respect to shorting post position have been studied by the Kin-Lu Wong [78a].

Similarly, the experimental work has been reported on the variation of the resonant frequency of the circular and rectangular patch antenna with respect to shorting post position ([81,82]). Mittra and Park has carried out the experimental work on the aperture coupled shorted rectangular microstrip antenna [79].
experimental work has been reported to reduce the cross-polarisation levels of the shorted microstrip by adding balanced feeding and shorting post[83]. G.Kumar et al. have also been studied the effect of the shorting post on circular, semicircular microstrip antenna[86a,86b].

A Green’s function based theory [86c] for analytically deriving the eigen frequency spectrum of shorting post microstrip patch antennas has been developed. This theory allows for comprehensive calculation of all relevant performance parameters of such antennas. The central role of the zero mode of the unloaded microstrip patch antennas for reducing the operation frequency of a shorting post microstrip patch antennas has been revealed and thoroughly discussed. The microstripline fed shorted rectangular microstrip antenna is studied experimentally by Sami H. et al. [86d].

In ([81],[82],[84]), single feed dual frequency compact microstrip antenna with a shorting pin is described.

STACKED ELECTROMAGNETICALLY COUPLED MICROSTRIP PATCH CONFIGURATION

Novel configurations are developed to widen the bandwidth of microstrip antennas, include the use of parasitic elements in the same plane as the microstrip patch [24], linear and nonlinear loading, travelling wave lines [23], and spiral antennas [22]. Out of all these, multilayer stacked configurations ([96],[161]) have been found to provide promising results as broadband microstrip antennas.

The multilayered configuration has been found to present an increased efficiency and bandwidth over the single layered structure. The first multilayered microstrip element has been described by Oltman [106] as an electromagnetically coupled (EMC) microstrip dipole which involves a novel feeding technique of exciting the printed dipole by an open ended microstrip transmission line in the same plane as the dipole or in the layer below the dipole. In analysing the EMC microstrip dipole, Oltman and Huener [107] have introduced an equivalent circuit where the coupling region between open ended transmission line and the dipole has been approximated by a pair of TEM coupled transmission lines and radiation losses by resistors at the ends of the dipole.

Katehi and Alexopoulos [100] have presented a method for the accurate modelling of the rectangular shaped printed circuit antennas parasitically by the strip
transmission line embedded in the substrate, and applied the technique to printed dipoles. The method of moments has been applied to determine the current distribution in the longitudinal direction from which the microstrip dipole self-impedance has been evaluated using the transmission line theory. Bandwidth enhancement methods using parasitic strip coplanar and parallel to the embedded microstrip transmission line, or located between the transmission line and the microstrip dipoles, have been discussed by Katehi et al. [101].

Stacking microstrip patches for dual frequency use has been investigated experimentally with circular disks by long and Walton [65] and with annular rings by Dahele et al. [12], Hall et al. [97] have stacked rectangular microstrip patches in two and three layer configurations to enhance bandwidth. Experimental work by Sabban [111], and Chen et al. [91] with two-layer stacked circular patches, and by Lee et al. ([102],[103]) with two-layer rectangular patches and by Bhatnagar et al. [90] with two-layer triangular microstrip patches, have reported wider bandwidth and higher efficiencies than those obtained with conventional single patch configurations.

Analysis of stacked microstrip patches based on equivalent transmission line model [23] as well as based on full wave spectral domain approach [87] have been reported. Using the Hankel transform, Araki et al. [87] have presented a numerical analysis of a circular microstrip disk antenna with a parasitic element. Resonant frequencies of the unloaded two-patch configuration are found by solving the equivalent transverse transmission line circuits for TE and TM components in the Hankel transform plane. Tulintseff et al. ([112],[113]) have used the method of moments with triangular basis functions to analyse the open structure of a two-layer circular microstrip antenna excited by an incident plane wave. Analysis of stacked rectangular microstrip patches using mixed potential integral equation, has been presented by Barlatey et al. [89]. Kastner et al. [99] have described a spectral domain iterative analysis of single and double layered microstrip antennas by conjugate algorithm to compute radiation patterns. Meck and Sauerer [105] have formulated coupled integro-differential equations, for stacked rectangular patches, which are solved in the spectral domain using method of moments. Davidovitz and Lo[95] have described a rigorous analysis of a circular patch antenna excited by a microstrip transmission line through proximity coupling, by applying Galerkin's method of moments in the Fourier Transform domain. Recently, Damiano et al.([93],[94]) and Luk et al. [104] have presented the analysis of offset multilayer
antennas based on the reaction integral equation solved in spectral domain by moment method using entire domain basis functions to take into account various shapes of the radiating elements.

**ELECTROMAGNETICALLY COUPLED SHORTED MS ANTENNA**

The techniques which have been discussed for the compact microstrip antenna, will disturb some of the antenna characteristics, such as, a shift in the radiation patterns, dip in the E-plane pattern, high cross-polarization levels in the H-plane and low radiation efficiency and consequently reduces the gain of the patch antenna. All these demerits of the shorted microstrip antenna (Compact microstrip antenna) will severely limit its applications. To come over these problems and also to enhance the bandwidth, electromagnetically coupled shorted structures have been reported.

A novel stacked rectangular shorted patch antenna has been studied both theoretically and experimentally ([116] [117]). These new antennas have significantly greater bandwidth (10%) than a conventional shorted patch.

An annular ring loaded (parasitically) shorted circular microstrip antenna has been studied by the Waterhouse ([114],[115]) and it has been observed that, bandwidth is increased to 10% and the cross-polarization levels have come down from $-1\, \text{dB}$ to $-11\, \text{dB}$ in the H-plane.

The stacked shorted patches for the dual frequency use with rectangular patches has been investigated for the 1800 MHz band by Ollikainen et al. [117] and with annular rings by Waterhouse et al.

**MICROSTRIP ARRAYS AND MUTUAL COUPLING**

One of the best features of microstrip antennas is the ease with which they may be formed into arrays. A wide variety of practical arrays with series feed, corporate feed, scanning and polarisation-agile configurations have been designed using the microstrip elements ([3], [23], [35], [126], [127], [129], [131], [134], [142], [143], [153], [155]). Usable analytical techniques for determining mutual coupling and other effects in microstrip arrays with conventional geometries are available in the literature ([132], [144], [145]).

While the study of microstrip antennas of conventional single patch configurations both as an isolated element and in infinite planar arrays has been
abundant ([122]. [139]. [147]), the study of characteristics of microstrip arrays with EMCP elements is limited. However, recently, for a two dimensional periodic array of idealised probe-fed stacked rectangular strips of finite width but infinite length, Stalzer et al.[156] considered E-plane scanning and demonstrated the dual tuned behaviour of the stacked structure leading to an iterative element synthesis in an array environment. Later Lubin and Hessel [140] have analysed, using Galerkin type solution, the behaviour of a stacked rectangular microstrip patch phased array element in the environment of an electronically scanning array with a 45° scan volume. Adjustment of antenna parameters has been indicated as a solution to improve the E-plane scan performance. A study on the stacked circular patch phased array has been reported by Tulintseff [113] and Aberle et al. [123].

Though mathematical models for microstrip antennas yield the resonant frequency and input impedance for isolated elements, usable analytical techniques to calculate the mutual impedance between microstrip antennas of various geometries are very few. Measured mutual coupling results for rectangular and circular patches in the L-band [133] and for circular patches in the C-band [146] are available in the literature. Mutual coupling measurements by Jedlika et al. [133] reveal that coupling levels encountered in microstrip antennas are low and may not cause any insurmountable problems in array design.

Pozar [33] has presented a full wave analysis of mutual coupling between two rectangular patches based on the moment method solution of the integral equation. Evaluation of mutual coupling between two circular patches is reported by Mohammadian et al. [145], Habashy et al. [132] and Entschladen et al. [131] using Full Wave analysis and cavity model/reaction theorem. A multiport network approach has been used for modelling mutual coupling effects in microstrip patches and arrays in a paper by Benalla et al. [124]. Some measurements conducted on mutual coupling between two rectangular patches in the C-band and the analysis based on C-band and the analysis based on the reaction concept by Mahdjoubi et al. [141] indicate that the coupling due to surface waves is insignificant for frequencies at least up to the C-band. Surface wave coupling between circular microstrip patches has been discussed by Bhattacharya et al. [125] and it is shown that the surface wave coupling decays much slower than the space wave coupling.
1.3 SCOPE OF THE PRESENT WORK

The experimental and theoretical investigations carried out on the two-layer electromagnetically coupled shorted circular and square microstrip antennas and their arrays are presented in this thesis. The following is a brief description of the complete work.

The radiation mechanism of a shorted (Compact) circular and square microstrip antenna is briefly mentioned, illustrating the limitations in its impedance bandwidth, radiation characteristics, based on the effects of substrate material and dimensional parameters of the feed probe and shorting post. So that, the shorted (Compact) for the small communication handset.

Various techniques have been described to improve the characteristics of the shorted (compact) microstrip antennas making use of electromagnetic coupled patch antennas. The annular ring and square ring coupled shorted circular, square microstrip antennas is described indicating its double resonance characteristics leading to a broad bandwidth and also a high gain with good pattern shape.

An exhaustive experimental study of the resonant frequencies, input impedance, impedance bandwidth and radiation characteristics of the EM coupled shorted microstrip antennas has been carried out for the both “normal” and “inverted” configurations. It is observed that, the impedance bandwidth is increased as high as 11% and cross-polarisation comes down from -1 dB to -15 dB ([118], [119], [120], [121]).

The study of an antenna element is not complete without investigating its performance in an antenna array. Experimental study has been carried out on shorted and EM coupled shorted microstrip antenna arrays.

The special considerations for microstrip antenna arrays as against conventional antenna arrays, has been described along with feed configuration losses in feed network and patches and mutual coupling cum scan blindness phenomenon. An experimental study has been carried out on the radiation characteristics and bandwidth of the EM- coupled shorted microstrip antenna arrays for both normal and inverted configurations.