Microstrip patch antennas are the most common form of printed antennas. A microstrip antenna (MSA) consists of a radiating patch on one side of dielectric substrate which has a ground plane on other side. The metallic patch is normally made of copper with a corrosion resistant metal such as gold, tin and nickel. Microstrip patch antennas have low profile configuration which can be easily made to host surface, capable of dual and triple frequency operations and they support both linear and circular polarization with single feed. Due to these advantages, these antennas are most suitable for aerospace and mobile applications. However, narrow bandwidth, lower gain, extraneous radiation from feed and junctions are their main disadvantages. To overcome these limitations, these antennas can be further loaded with stubs, shorting pins, diodes to obtain compactness, dual frequency operation, frequency agility and polarization control. Thus these antennas are finding increasing applications in the commercial sector of the industry especially in GPS (Global Positioning system), SDARS (Satellite Digital Audio Radio Services) and WLAN (Wireless Local Area Networks).

1.1 Origin

Microstrip geometries that radiate electromagnetic waves were originally contemplated in early fifties. The realization of a microstrip like antenna integrated with microstrip transmission line was developed in 1953 by Deschamps [1]. Gutton and Bassinot [2] patented a microstrip design in 1955. First practical antennas were fabricated after 20 years. Howell [3] and Munson [4] developed the first practical antenna. Since then an extensive research on microstrip antennas aimed to become most innovative topics in antenna theory and design. Thus these antennas are increasingly finding applications in wide range of modern microwave systems.

1.2 Methods of Analysis and Radiation Mechanism

There are various methods for analysis of microstrip antennas. The analysis can be broadly classified into two groups. Reduced analyses refer to microstrip antenna models that introduce one or more significant approximations to simplify the problem. These include (i) the transmission line model [5,6] which models the
transmission line section with lumped loads, (ii) the cavity model [5 - 7] which uses a magnetic wall boundary condition approximation for the periphery of the patch and (iii) the multiport network model [6] which generalizes the cavity model. The original transmission model was prepared by Munson [4]. This model represents the microstrip antenna by two slots of width $W$ and height $h$, separated by a transmission line of length $L$. Most of the electric field resides in the substrate and parts of some line in the air. As a result, the transmission line cannot support pure TEM mode of transmission and dominant mode of propagation is quasi-TEM mode. The transmission model is basic of all the models and it gives good physical insight. However, it accuracy is limited so an improved transmission line model was given by [8]. This model can be applied only to rectangular and square patches. It is not possible to analyze proximity coupled and aperture coupled microstrip fed by this method. In GTLM (Generalized Transmission Line model) approach the transmission line sections which may be non uniform on either side of current source are converted into $\pi$ network. This model has been described in detail [9,10] with different approaches. The patch shapes studied using this model include rectangular patch [9,10], circular patch [11], ring [12], annular and circular sectors [13]. Since all configurations such as proximity coupled, aperture coupled and stacked patches can not be analyzed with this model so the next model to overcome was the cavity model. Cavity model was advanced by Lo et al. [14]. The cavity model becomes a natural choice to analyse the patch antennas as it is the approximate model which leads to reactive input impedance and does not radiate any power. In cavity model, the region between the patch and the ground plane is modeled as a cavity bounded by magnetic wall along the periphery and by the electric wall from the top and bottom sides. When the microstrip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. 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. The repulsive mechanism is between the like charges on the bottom surface of the patch which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, current 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 current to be below the patch surface. The cavity model has been applied to a number of patch shapes, including rectangular patches [15,16], circular patches [17-19], equilateral triangles [20], circular rings [21], annular and circular sectors. The multiport network model [MNM] is the extension of cavity model in which the impedance boundary conditions at the periphery is forced explicitly [6]. In this method the mutual coupling between various edges is taken into account. The fields in the interior and exterior region are modeled separately. The interior region is modeled as a multiport planar circuit, with ports located along the periphery. The fields in the exterior region, which includes the fringing fields, radiation fields and surface wave fields are represented by load admittances. The multiport impedance matrix of the patch is obtained from its 2-D Green's function. These models were the first to be developed for microstrip antennas and have been extensively useful for practical designs, as well as providing a good intuitive explanation of the operation of microstrip antennas.

The second group of analysis technique namely numerical techniques that account for dielectric substrate in a rigorous manner are referred to as full wave solutions. These models assume that the substrate is infinite in extent in lateral dimensions and enforce the proper boundary conditions at the air – dielectric interface. Harrington [22] introduced the Method of Moment (MOM) technique, which is applied to electromagnetic problems. These methods are accurate and versatile as these include the surface wave, space wave radiation and mutual coupling into account.

However, these methods are numerically intensive, complex, time consuming and require careful programming in order to be computationally efficient. These techniques provide little of the physical insight required for antenna design. The first groups of techniques are simple to use and provide good physical insight. In cavity model, the analysis problem reduces to that of finding the edge voltage distribution for a given excitation and for a specified mode.

For a thin patch, this model offers accurate results suitable for most engineering applications. Hence, this model can form the basis of study of radiation mechanism of loaded circular disk and annular ring substrates.
1.3 Circular Disc and Stacked Circular Disc

The circular disc is characterized by a single parameter i.e. its radius \( a \). Thus it is simplest geometry since other shapes require more than one parameter to describe them. The circular disc antenna has been studied extensively [23-29]. Circular disk antennas has been studied by various analytical methods viz. cavity model [25,27], the generalized transmission line model [9,11,12], mode matching with edge admittance [24,25] and Finite Difference Time Domain (FDTD) [29]. The cavity model is found to simple and useful in design of structure. As elaborated in the earlier section, in the cavity model the interior region of the patch is modeled as a cavity bounded by electric walls on the top and bottom and a magnetic wall all along the periphery. The following are the basic assumptions for thin substrates;

(i) The fields in the interior region do not vary with \( z \) (i.e. \( \partial \phi / \partial z = 0 \)) because substrate is very thin.

(ii) The electric field is \( z \) directed only and the magnetic field has only the transverse components in the region bounded by the patch and the ground plane i.e. the magnetic field essentially has only \( \rho \) and \( \phi \) components.

(iii) The electric current in the patch has no component normal to the edge of the patch, which implies that the tangential component of magnetic field \( \vec{H} \) along the edge is negligible.

Thus, the fields within the dielectric region of the microstrip cavity, corresponding to \( \text{TM}_{\text{amp}} \) modes, can be determined by solving the wave equation in a cavity (Since field distribution along \( z \)-axis is constant, the index \( p \) is omitted in further references). For no excitation current, the wave equation for the electric field can be written as

\[
(\nabla^2 + k^2) \vec{E} = 0
\]

where \( k = \frac{2\pi}{\lambda} \)

After application of boundary conditions, the fields are derived. For each mode configuration, a radius can be found that results in a resonance corresponding to the zeroes of the derivative of the Bessel function. Thus, the cavity model is used to explain the circular disc antennas and other geometries. There has been a great
demand for wide-band antennas to be used in wireless communication applications so that a large amount of data can be transmitted in a short interval of time.

Bandwidth of microstrip antennas can be enhanced by different methods such as stacking, loading and using multilayered structures. For early versions of the direct feed stacked patch antenna only moderate bandwidth less than 15% were achieved. The true potential of the direct feed stacked patch antenna could be realized in the late 1990’s. An accurate analysis of probe fed stacked patch with rigorous full wave analysis based on spectral domain integral equation approach was devised. These formulations accurately model the discontinuity associated with the probe-patch interconnect. Stacking the antenna in multilayered configuration introduces additional resonance in the frequency resulting in the wide bandwidth and dual frequency operation. Stacked patches have been extensively studied [33-38] to obtain wide bandwidth and dual frequency operations. Tulinsteff et al. [33] presented the analysis of a probe-fed stacked circular microstrip antenna. The rigorous analysis based on dyadic Green’s function formulation has been used. The mixed boundary value problem has been reduced to a set of coupled vector equations. 13% (10 dB bandwidth) and dual frequency operation has been obtained. The central feeding scheme has been used to obtain two band responses in stacked microstrip square antenna [34]. The upper patch has been fed by coaxial probe extended through a hole in the centre of the ground plane and lower patch is fed from above forming a small loop from the centre to 50 Ω feed point on the upper patch. Good impedance matching of less than -10 dB has been obtained at two frequencies with no large pattern imbalance. Aperture coupled stacked microstrip patch antenna has also been studied [37,39]. A broadband circularly polarized stacked patch antenna element and its sub array, with high efficiencies at 10 GHz, has been presented by Chung et al. [42]. In addition to low boresight axial ratios, the subarray has measured bandwidth of about 25%. Antenna efficiency is 89% around center frequency for single element where as subarray has efficiency of 71%.

The stacked microstrip ring antenna for dual frequency behavior and improved bandwidth has been studied [35,38]. The cavity model for single microstrip antennas has been extended with some modifications for stacked geometry to account
coupling between upper and lower cavities, fringe fields, dispersion effects and effective loss tangent of dielectric material.

1.4 Ring Resonator

Microstrip ring resonator was first proposed in 1969 for the measurement of phase velocity and dispersive characteristics of a microstrip line. In first 10 years most applications were concentrated on the measurements of characteristics of discontinuities of microstrip lines. Sophisticated field analysis was developed to give accurate modelling and prediction of ring resonator. In 1980, applications using ring circuits as antennas and frequency selective surfaces emerged. Microwave circuits using rings for filters, oscillators, mixers, baluns and couplers were also reported. Some unique properties and excellent performances had been demonstrated using ring circuits built in coplanar waveguide. The integration with various solid state devices was also realized to perform tuning, switching, amplification, oscillation and optoelectronic functions.

There are certain advantages of using ring antennas over other structures. The ring resonator would only support waves with integral multiple of the guided wavelength equal to the mean circumference. Ring microstrip antennas are alternatives to standard rectangular and circular disks. These antennas are geometrically and electrically an intermediate configuration between a printed loop and patch [43]. The ring antennas have smaller size as compared to circular patch when both are operated in lowest mode. The annular ring antenna can be combined with a second microstrip element. Thirdly, the separation of the modes can be controlled by the ratio of outer to inner radii. Finally, it has been found that by operating in one of the higher order broadside modes, i.e. TM_{12}, the impedance bandwidth is several times larger than is achievable in other patches. It has been shown that the structure is a good resonator (with very little radiation) for TM_{m1} mode (m odd) and a good radiator for TM_{m1} modes (m even).

The annular microstrip ring antenna has been studied extensively [44-52]. Various methods of analysis have been applied to the annular ring antenna including the cavity model [6,44-47], generalized transmission line model [12], analysis in the Fourier-hankel transform domain [49] and the method of matched asymptotic
expansion [50]. The field analysis “magnetic-wall model” for microstrip ring resonators was firstly introduced in 1971 by Wolff et al.[47]. In 1976, Ownes improved the magnetic-wall model [51]. Pinztos et al. [52] presented a rigorous solution in 1978 based on stationary principle. Wu et al. [53] obtained the mode chart for the fields in magnetic-wall model. Sharma et al. [54] carried out a numerical solution using the spectral domain method. Wolff et al. used perturbation analysis to design the open end closed ring microstrip resonators [55]. So far, only the annular ring resonator has the field theory derivation for its frequency modes. For the square or the meander ring resonators, it is difficult to use the magnetic-wall model to obtain frequency modes of these ring resonators because of their complex boundary conditions. The field analysis based on electromagnetic theory is complicated and difficult to implement in a computer-aided-design (CAD) environment. Chang et al. [56] first proposed a straightforward but reasonably accurate transmission-line method that can include gap discontinuities and devices mounted along the ring. Gopalkrishnan et al. [57] further improved this method with a distributed transmission-line method that includes factors affecting resonances such as microstrip dispersion, the curvature of resonator and perturbation. The distributed transmission line method can accommodate many solid-state devices, notches, gaps and various discontinuities along the circumference of ring structure. The ring antenna has been rigorously analyzed using Galerkin’s method [58,59]. It has been concluded that TM$_{12}$ mode is the best mode for antenna applications. Another rigorous analysis of probe-fed ring antenna has been introduced by Kokotoff et al. [60]. Numerical method based on full-wave spectral-domain method of moment has been used to model the connection between probe feed and ring antenna.

Active antennas have received great attention because they offer savings in size, weight and cost over conventional designs. These advantages make them desirable for application in microwave systems such as wireless communications, collision warning radars, vehicle transceiver, self-mixing Doppler radar for speed measurement and microwave identification systems [61,62]. Ring resonator has also been proposed as a radiator for medical applications [63] and used to measure the dielectric constant of the substrate material [47].
1.5 Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. The feeding methods can be classified into two categories; contacting and noncontacting. In the contacting method, the RF power is fed directly to the connecting element such as microstrip line. In microstrip line feeding, coaxial probe are the contacting type techniques. In the other type, electromagnetic feed coupling is done to transfer power between the microstrip line and radiating patch. The aperture coupling and proximity coupling are of other type. In the microstrip line feeding, a conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this type of feed has the advantage that the feed can be etched on the same substrate to provide a planar structure. This technique provides ease of fabrication, simplicity in modelling as well as impedance matching. If we use a thick dielectric substrate, surface waves and spurious wave radiations also increases, which hamper the bandwidth of the antenna. This feed radiation also leads to undesired cross-polarized radiation. The coaxial feed is very common technique used for feeding microstrip antenna. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that feed can be placed at any desired location inside the patch in order to match with its input impedance. This method is easy to fabricate and has low spurious feed radiation. The disadvantage of this method is that it provides narrow bandwidth and it is difficult to model since a hole has to be drilled in the substrate. In aperture-coupled feed, the ground plane separates the radiating patch and the microstrip feed line. The coupling aperture is centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers. Electromagnetic coupling scheme is also called as proximity coupled feed. Two dielectric substrates are used such that feed line is in between the two substrates and the radiating patch is on the top of upper substrate. The main advantage of this feed technique is that it eliminates spurious feed
radiation and provides very high bandwidth (as high as 13 %) due to overall thickness of the microstrip patch antenna. The major disadvantage of this feeding is that it is difficult to fabricate because two dielectric layers need proper alignment. Coupling between the patch and the microstrip line is capacitive in nature. Pozar et al. [64] proposed an alternative method of obtaining enhanced bandwidth from a microstrip antenna, using a microstrip feed line proximity-coupled to a patch antenna printed on a superstrate above the feedline. A small tuning stub is also required so that an enhanced bandwidth of 13 % is obtained. Oltman et al. [65] gave different electromagnetic coupling (EMC) microstrip dipole configurations, which employ varying amount of electric and magnetic coupling to radiate with varying degree of efficiency. Transmission line model was used to explain the coupling mechanism from the circuit viewpoint, while a moment method solution has been used to provide insight from field viewpoint. These two methods were used as approximations to the actual situations, however they provided the valuable information on the physics involved with this type of radiator. Theoretical viewpoint of EMC microstrip dipole and arrays has been presented and has been used with good success. Rectangular shorted patch antenna has been designed with proximity coupling to obtain wideband performance and size reduction [66]. The patch size is reduced to 25% to full size patch with over 30% matching bandwidth. 16 elements array has also analyzed with different feeding arrangements indicating an improvement in the array performance. The achieved gain in this case is 15%.

A remarkable amount of work needs to be done on electromagnetic coupled microstrip patch antennas as this is the best method of feeding microstrip antennas.

1.6 Short Loaded Antenna

Antennas which are used in wireless local area networks (WLANs) needs operation at two or more discrete bands and an arbitrary separation of bands. It is not possible to achieve these objectives from the basic microstrip antennas having regular shapes. Hence to obtain these applications we can suitably load the regular microstrip structures. Loading of microstrip antennas is used to obtain circular polarization, frequency tuning, broadbanded, impedance matching, radiation pattern control etc. Loading can take various forms such as stub loading, slots, shorting posts, parasitic
couplings, substrate loading, superstrate cover, resistors, capacitors and diodes. A
good overview of loaded microstrip structures has been given by Garg et al. [66]. A
microstrip antenna can be easily made to resonate at many frequencies corresponding
to a $\text{TM}_{ap}$ mode. If the patch is loaded (e.g. with strategically placed shorts), the field
and current distributions for various modes will be disturbed and therefore their
characteristics will change. This change will depend on the amount of load and the
mode under consideration. Loading can lead to polarization diversity [67], frequency
agility [67,68] and radiation pattern control [69-71]. Shorting pins can be used to load
the microstrip antenna. Shorting pins will tend to give compactness, tunability and
improve frequency operations. Microstrip antennas of different shapes loaded with
shorting pins [72-75] has been extensively studied. Depending upon the applications,
a shorting pin may be located at the edge or at the centerline of the patch. The analysis
of post loaded microstrip antenna has been carried out using the transmission line
model [67,76], cavity model [77,78], multiport network model [79], integral equation
approach [80] and FDTD technique [81,82]. Wong et al. [83] presented a triangular
antenna loaded with shorting pin which can significantly reduce the size of antenna at
a given frequency. The antenna without shorting pin resonates at 1.9 GHz whereas
when loading the frequency of antenna is much lower than 1.9 GHz. Dual-frequency
has been obtained from H - shaped microstrip antenna loaded with a shorting pin [84].
This antenna in comparison to a conventional rectangular patch antenna can achieve
both significant reduction of antenna size and a dual-frequency operation with a single
feed. Finite difference time domain (FDTD) method is used for theoretical analysis.
It has been seen that various frequency ratios (1.91 - 4.23) are obtained by varying the
design parameters of this antenna. Dual frequency microstrip antenna with a single
feed using a shorting pin has been presented by Shan et al. [85]. The design has been
first applied to a rectangular microstrip antenna. By short-circuiting the antenna at
proper positions the first two frequencies with same polarization plane can be excited
with good matching conditions. The first ($f_1$) and second ($f_2$) frequencies are
respectively in the range 950-722 MHz and 1900-2310 MHz which indicates the
frequency ratio tunable in the range 2.0-3.2. The design is then applied to an
equilateral triangle which shows a tunable frequency ratio of about 2.5-4.9. The two
resonant frequencies strongly depend on the position of shorting pins.
Circular microstrip antenna with off-centered posts has been proposed by De [86]. In this, treatment has been developed for single or multiple posts when the posts are symmetrically located i.e. equi-spaced along the circumference of circle concentric with the patch radiator. The resonance is dependent on radial distance of posts from the centre, the angular location and the radius of posts. The dual band antenna can be designed with flexible band separation. In case of asymmetric loading the angular dependence vanishes and $(1,1)$ is the dominant mode. An analytical theory for the eigenfrequencies and eigenmodes of shorting post loaded microstrip antennas has been presented [87]. It is shown that the zero mode of the unloaded MSA plays a central role for reducing the lowest operating frequency of the loaded microstrip patch antennas. The lowest values for the resonant frequency have been obtained when positioning the shorting post at the edge of the patch. In general, the resonant frequencies obtainable from a loaded circular patch are larger than those of a rectangular patch of equal cross section. It is also seen that the sensitivity of the resonance frequency against variations of the shorting-post position of the circular patch is stronger than in the rectangular patch.

Recently an approximate analysis of short circuited ring patch antenna has been presented in [88]. The analysis is based on cavity model and different parameters of antennas such as the resonant frequency, fields, radiation pattern, and input impedance of a short-circuited ring working at $TM_{01}$ mode are calculated. In a recent work [89], neural networks have been used for the first time in short circuited ring patch antenna working at $TM_{01}$ mode. The dependence between the fundamental antenna parameters such as internal radius, external radius, permittivity of the substrate has been studied. Finally a neural network has been proposed for the analysis of these antennas and this tool is useful as it provides advantages in computation time with negligible error in real terms.

In the light of the above discussions, significant amount of work can be done for a loaded annular ring microstrip antenna. Also an accurate model of such antenna is necessary to predict the various performances. As mentioned earlier, the full-wave methods are rigorous and computationally resource intensive. An elegant alternative method giving insight to the problem is therefore worth searching. Theoretical modelling for symmetric and asymmetric loaded annular patch is not reported in
literature and is therefore attempted in this present work. This analysis may lead to a practical design where the shorting posts are replaced by switching diodes positioned symmetrically about the feed. A pair of switching diode can be electronically switched on/off based on the operating frequency desired.

1.7 Fabricated Antenna and Experimental set up

In the Present work an analytical numerical model is developed for the circular disc and ring resonators. This analysis is further extended to stacked circular disc antenna and shorting posts in ring resonators. Proximity coupled antenna is also analytically modeled. The validation of the analytical model is carried out by comparison with the standard software simulator (IE3D™) results. Representative results were experimentally validated with the existing facilities. The return loss measurements were tested using Vector Network analyzer model no 8714ET.

Photograph of RF Network Analyzer (8714 ET) used for measurements

The Block diagram of the test setup is given in the figure1.1. The calibration of the Network analyzer is first done by using open, short, 50ohm with terminator. After the
The basic specifications of the analyzer are:

<table>
<thead>
<tr>
<th>Type</th>
<th>Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integral Signal Source</td>
<td>Yes</td>
</tr>
<tr>
<td>Integral Test Set</td>
<td>T-R Parameter</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>300 kHz - 3 GHz</td>
</tr>
<tr>
<td>Source Frequency Resolution and Accuracy</td>
<td>1 Hz and 0.0005%</td>
</tr>
<tr>
<td>Minimum Output Power</td>
<td>0.001 Watts</td>
</tr>
<tr>
<td>Maximum Output Power</td>
<td>19.9526 mW</td>
</tr>
<tr>
<td>Output Accuracy</td>
<td>1 dB</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>50 Ohm</td>
</tr>
<tr>
<td>No. of Receiver Channels</td>
<td>2</td>
</tr>
<tr>
<td>Receiver Minimum Frequency</td>
<td>300 kHz</td>
</tr>
<tr>
<td>Receiver Maximum Frequency</td>
<td>3 GHz</td>
</tr>
<tr>
<td>Minimum Dynamic Range</td>
<td>100 dB</td>
</tr>
<tr>
<td>Maximum Dynamic Range</td>
<td>100 dB</td>
</tr>
<tr>
<td>Maximum Input Decibel</td>
<td>20 dBm</td>
</tr>
<tr>
<td>Input Connector Type</td>
<td>Type-N(f)</td>
</tr>
</tbody>
</table>

**Figure 1.1** Block Diagram for measurement of Reflection Coefficient
Photograph of Symmetrically loaded Annular Ring Antenna with posts

calibration is completed then the test antenna is connected to the network analyzer and the measurement is done by selecting the frequency range of the interest.

Figure 1.2 Calibration Set up
1.7 Outline of Thesis

Pursuing the introductory chapter the rest of thesis is organized as follows;

Chapter II presents the evaluation of input impedance of circular patch by using cavity model. Various parameters such as wall admittance and radiation parameters are evaluated. The fields in the regions inside the circle are evaluated from the solution of the appropriate scalar Helmholtz equation for the TM modes. Evaluation of the constants using the boundary conditions leads to a transcendental equation. The resonant frequencies for different modes are determined from the equation of resonant frequency of circular patch antenna. In the proposed model, the impedance expression of end correction network suggested by Zheng et al. [90] has been utilized. The theory is further extended to find out the input impedance of stacked circular disc. The upper patch is considered as uncoupled cavity with an air gap. For the upper patch the effective dielectric constant is given by [91]. The main and fringing capacitances are used for the calculation of effective dielectric constant. Radiation parameters are calculated by magnetic current density approach.

Chapter III presents the method of evaluation of input impedance of annular ring antenna fed with coaxial line feeding. The cavity model along with circuit theory is used to find out input impedance. The fields inside the cavity appearing in the expression for self reaction are expressed as a superposition of normal cavity modes. The amplitude coefficients appearing in the series are determined in terms of wall admittance and the conductor losses. The dielectric loss is taken into account by assuming that permittivity is complex. Computed results are compared with the presented experimental results of Garg et al. [49] and simulated results obtained from moment-method based solver IE3D [92]. The analysis is further extended to calculate the resonant frequency of asymmetrically loaded annular ring antennas.

In chapter IV, the eigen frequencies of symmetrically loaded annular microstrip antenna are evaluated. The shorting is done with the help of posts, the impedance per unit length for small cylindrical circular current distributions is given as [93]. A circular disk antenna with off-centred shorting posts proposed by De [86] is used. The resonant frequency of the loaded patch is computed and the results are compared with measurements. It is predicted that TM01 is the dominant mode of these antennas. This configuration results in a compact antenna, which is electronically
tunable over a wide range of frequencies. The input impedance of loaded microstrip antenna is presented. The analysis is same as described in chapter III. The computed results are compared to the simulated results; the simulation is done on IE3D software based on method of moment. The radiation parameters are also calculated and plotted. The results show that loading of antenna with the help of shorting pins will help to enhance the bandwidth and as the size of antenna is also reduced. These types of antennas have key role in communication.

In chapter V, the evaluation of input impedance of annular ring antenna fed by electromagnetic coupling. A microstrip line of length ‘l’ and width ‘w’ is used to feed the antenna. The method is based on cavity model in conjunction with circuit theory. It is shown that the proposed structure can act as a compact antenna with proper impedance matching.

The last chapter is the summary of work carried out.
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