Antennas are like electronic eyes and ears: our links to the world and the space beyond. In a wireless communication system they act as interface between space and circuitry. Although some antennas like the dipole and loop have changed little since Hertz invented them, many new types have been developed and resulted in an antenna family of great diversity. The recent explosion in commercial applications involving RF and microwave systems is fueling customer demand for small, low-cost, easy-to-use systems. Microstrip antennas are thin printed-circuit antennas that allow transmission and reception of electromagnetic energy using a planar structure.

The concept of microstrip radiators was first proposed by Deschamps as early as 1953. Howell and Munson developed the first practical antennas in the early 1970's. Microstrip antennas due to the diverse range of applications are now established as a separate topic in their own right within the broad field of microwave antennas.

Microstrip antennas popularity stems from the fact that the structure is "planar" in configuration and enjoys all the advantages of printed circuit technology. It is essentially a printed circuit board with all the power dividers, matching networks, phasing circuits and radiators, photo etched on one side of the board. The other side of the board is a metallic ground plane and thus the system can be directly attached to a metallic surface on an aircraft or missile.

The future demand for microstrip antennas is expected to escalate because of market growth in mobile satellite communications, cellular telephone networks, direct broadcast television, wireless local area networks and intelligent vehicle highway systems.
1.1 PRINTED STRUCTURES

The need to replace bulky, heavy and difficult to manufacture waveguide structures was one of the main motivations for the endeavors, which lead to the invention of printed structures. Printed structures are made of one or several dielectric layers with metallic traces printed on. Early structures back in the 1950's were essentially triplate or strip lines with one thin metallic strip enclosed by two dielectric layers with metallisations on the outside as shown in Figure 1.1(a). Subsequently, other line structures were invented: microstrip lines (Figure 1.1(b)) where one of the dielectric layers was removed, slotlines (Figure 1.1(c)) where only one side of the dielectric is metallised and coplanar wave-guides as a symmetric slotline (Figure 1.1(d)). Other enclosed lines are the suspended line (Figure 1.1(e)), the inverted line (Figure 1.1(f)), and the finline (Figure 1.1(g)). Each type has its own advantages and disadvantages; today the most widely used type is probably the microstrip line. This line is comparatively easy to manufacture and has a low weight.

1.2 WAVES IN MICROSTRIP STRUCTURES

Depending on the actual structure, four wave types can exist in a planar structure: space waves, surface waves, leaky waves, and guided waves as shown in Figure 1.2. If the structure is to be used as an antenna, most of the energy has to be converted into space wave. For transmission lines, most of the energy should be held in a guided wave. The other two wave types, the surface and the leaky wave represent mostly losses. Guided waves (A) are confined in the dielectric layer between two metallisations. Space Waves (B) are transmitted upward in an angle $\theta_{sw}$ between 0 and $\pi/2$. Leaky Waves(C) originate from waves transmitted from the top layer to the ground plane at an angle $\theta_{lw}$ smaller than the critical angle $\theta_{lim} = \sin^{-1}(1/c_r)$. After being reflected from the ground plane, they are partially reflected by the dielectric-air interface, but some energy leaks out of the substrate (hence leaky waves). Surface waves (D), are waves directed slightly downward
from the top layer at an angle $\theta_{sw}$ larger than $\theta_{lim}$. They are totally reflected by the
dielectric-air interface (total reflection condition). The fields are trapped in the
dielectric layer (the waves in optical fibres are the best known surface waves),
however can cause unwanted interaction (crosstalk) or degradation of the
radiation pattern by being diffracted and reflected at the edges of the dielectric
layer.

Figure 1.1 Various printed line types (a) Stripline (b) Microstrip line (c) Slotline
(d) Coplanar line (e) Suspended line (f) Inverted line (g) Finline

Figure 1.2 Waves in Microstrip structures (A) Guided Waves (B) Space Waves
(C) Leaky Waves (D) Surface Waves
1.3 MICROSTRIP ANTENNA

Microstrip antenna consists of a planar radiating structure over a ground plane separated by an electrically thin layer of dielectric substrate as shown in Figure 1.3. The patch conductors can assume virtually any shape but conventional shapes are generally used to simplify analysis and performance prediction. The dielectric constant \( c_r \) of the substrate should be low so as to enhance the fringe fields, which account for the radiation.

![Figure 1.3 Microstrip Antenna Configurations](image)

1.3.1 Radiation fields of microstrip antennas

Radiation from microstrip antennas can be understood by considering the simple case of a rectangular microstrip patch spaced a small fraction of a wavelength above a ground plane as shown in Figure 1.4 (a). Assuming no variations of the electric field along the width and thickness of the microstrip structure, the electric field configuration of the radiator can be represented as shown in Figure 1.4 (b). The fields vary along the patch length, which is about half a wavelength \( (\lambda/2) \). Radiation is mainly due to the fringing fields at the open circuited edges of the
patch. The fields at the end can be resolved into normal and tangential components with respect to the ground plane. Since the patch is \( \lambda/2 \) long the normal components are out of phase and the far field produced by them cancels in the broad side direction. The tangential components are in phase and the resulting fields combine to give maximum radiated field normal to the surface of the structure. Therefore the patch may be represented by two slots half wavelength apart excited in phase and radiating in the half space above the ground plane.

**Figure 1.4** (a) Rectangular Microstrip Patch Antenna (b) Side View (c) Top View
1.3.2 Advantages and Disadvantages

Microstrip antennas are compatible with microwave integrated circuits. The solid state circuits such as oscillators, phase shifters etc. and the feedlines and matching networks can be directly added to the antenna structure. They have low weight and low volume. Their low profile planar nature helps to make these antennas conformal with the body of the systems such as rockets, satellites and missiles so that they can be mounted without much alteration to the parent body. Linear and circular polarizations are possible by adjusting the antenna parameters, feeding networks or by placing shorting pins at appropriate points. Dual frequency microstrip antenna can be easily produced by cutting slots or stubs, using shorting pins, loading of reactive components etc.

Microstrip antennas suffer from some drawbacks, which limit their application in certain specified areas. The most serious disadvantage is the narrow impedance bandwidth, which is only of the order of a few percent. The power handling capacity is lower than that of conventional microwave antennas; the gain is very low; the isolation between the radiator and the feed element is also poor.

1.3.3 Applications

Some notable applications for which microstrip antennas have been developed include:

- Satellite Communication
- Doppler Radars
- Missile Telemetry
- Remote sensing
- Biomedical Radiator
- Phased Array Radars
Present applications of this technology are growing most rapidly in the commercial sector also. While specifications for defense and space application antennas typically emphasize maximum performance with little constraint on cost, commercial applications demand low cost components, often at the expense of reduced electrical performance. Some of the commercial systems that presently use microstrip antennas are listed in the table below:

<table>
<thead>
<tr>
<th>Application</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Positioning System</td>
<td>1575 MHz and 1227 MHz</td>
</tr>
<tr>
<td>Paging</td>
<td>931-932 MHz</td>
</tr>
<tr>
<td>Cellular Phone</td>
<td>824-849 MHz and 869.895 MHz</td>
</tr>
<tr>
<td>Personal Communication Systems</td>
<td>1.85-1.99 GHz and 2.18-2.20 GHz</td>
</tr>
<tr>
<td>GSM</td>
<td>890-915 MHz and 935-960 MHz</td>
</tr>
<tr>
<td>Wireless Local Area networks</td>
<td>2.40-2.48 GHz and 5.4 GHz</td>
</tr>
<tr>
<td>Cellular Video</td>
<td>28 GHz</td>
</tr>
<tr>
<td>Direct Broadcast Satellite</td>
<td>11.7-12.5 GHz</td>
</tr>
<tr>
<td>Automatic Toll Collection</td>
<td>905 MHz and 5-6 GHz</td>
</tr>
<tr>
<td>Collision Avoidance Radar</td>
<td>60 GHz, 77 GHz, and 94 GHz</td>
</tr>
<tr>
<td>Wide Area Computer Networks</td>
<td>60 GHz</td>
</tr>
</tbody>
</table>

1.4 EXCITATION TECHNIQUES

The feed has the task to couple the electromagnetic wave propagating on a transmission line to the radiating element as efficiently as possible. The antenna input impedance is greatly controlled by the location of the feed point. The variation of feed location may produce a small shift in resonant frequency, but radiation pattern remains unaltered.

1.4.1 Coaxial feed

Here the outer conductor is connected to the ground plane and the centre conductor is connected to the patch as shown in Figure 1.5 (a). Due to the non-
monolithic structure, however, the fabrication is more difficult than with planar feeding methods. Furthermore, the spurious radiation of the probe is in some cases unacceptable.

### 1.4.2 Microstrip feed

Easier to fabricate than the coaxial feed, the edge (Figure 1.5 (b)) and the inset feed (Figure 1.5 (c)) has the advantage that the whole antenna including the feed is one piece, the structure is monolithic. Especially at high frequencies, the spurious radiation from the feed line can degrade the radiation efficiency and the radiation pattern. The inset feed allows some control over the impedance, at the cost of increased spurious radiation.

### 1.4.3 Proximity Coupled feed

This feed is also called electromagnetic (EM) coupled feed, as the EM energy is coupled by placing the feed and the radiating element in close interaction with no conducting connection. This is achieved by placing an additional substrate with the radiating element on top of the feed line as shown in Figure 1.5 (d). By doing so, the spurious radiation of the feed can be reduced so that the radiation pattern is less affected by the feed.

### 1.4.4 Aperture Coupled feed

The spurious radiation of the feed can be completely shielded by using an aperture coupled antenna. The antenna is mounted on the other side of the ground plane of the feed; the EM energy is coupled through an aperture to the patch as shown in Figure 1.5 (e).
Figure 1.5 Microstrip antenna feeding

(a) Coaxial feed

(b) Microstrip edge feed

(c) Microstrip Inset Feed

(d) Proximity Coupling

(e) Aperture Coupling
1.5 SUBSTRATE MATERIALS

Choice of the substrate materials depends on the application. Conformal antennas require flexible substrates; low frequency antennas require high dielectric constant substrates to reduce the size of the antenna.

Substrate choice and evaluation is an essential part of the design procedure. Properties like dielectric constant ($\epsilon_r$) and loss tangent ($\tan\delta$) and their variation with temperature and frequency, dimensional stability with processing, thickness uniformity of the substrate, thermal coefficient and temperature range must be involved in these considerations.

A large range of substrate materials is available in the market with dielectric constants ranging from 1.17 to 25 and loss tangents from 0.0001 to 0.004. Earlier microstrip antennas used plastic substrates or in some cases alumina, but in recent years the use of low permittivity substrate is most common. This reduces the surface wave effects but feeder radiation is then more difficult to suppress.

The substrate dielectric constant, loss tangent and dimensions are functions of temperature. So in the design of antennas for use in high speed missiles, rockets etc., the changes in $\epsilon_r$ and $\tan\delta$ with temperature should be known. This is important because the bandwidth is narrow. Dielectric constant and loss tangent also vary with frequency. The change in $\epsilon_r$ is very small but $\tan\delta$ varies much with frequency. So, for higher frequencies substrate with low losses are developed.

Substrate technology thus offers a challenge to material manufacturers to create low-cost high-performance stable substrates.
1.6 MICROSTRIP ANTENNA CONFIGURATIONS

Microstrip antennas can be divided into three basic categories: microstrip patch antennas, microstrip traveling wave antennas, and microstrip slot antennas. Their characteristics are discussed below.

1.6.1 Microstrip Patch Antennas

A microstrip patch antenna consists of a conducting patch of any planar geometry on one side of a dielectric substrate backed by a ground plane on the other side. Various microstrip patch configurations are shown in Figure 1.6.

1.6.2 Microstrip Traveling Wave Antennas

Microstrip Traveling Wave Antennas consists of chain shaped periodic conductors or an ordinary long TEM line which also supports a TE mode, on a substrate backed by a ground plane. The open end of the TEM line is terminated in a matched resistive load. As antenna supports traveling waves, their structures may be designed so that the main beam lies in any direction from broadside to endfire. Various configurations are shown in Figure 1.7.

1.6.3 Microstrip Slot Antennas

Microstrip slot antenna comprises of a slot in the ground plane fed by a microstrip line. The slot may have the shape of a rectangle, a circle or an annulus as shown in the Figure 1.8.
Figure 1.6  Microstrip Patch Antennas

Figure 1.7  Microstrip Traveling Wave Antennas

Figure 1.8  Microstrip Slot Antennas
1.7 BASIC CHARACTERISTICS OF RECTANGULAR PATCHES

Rectangular geometry can be analyzed by straightforward application of the cavity model. It is characterized by length ‘a’ and width ‘b’.

The electric field of a resonant mode in the cavity under the patch is given by

\[ E_z = E_0 \cos\left(\frac{m \pi x}{a}\right) \cos\left(\frac{n \pi y}{b}\right) \]

where \( m, n = 0, 1, 2 \ldots \) (1)

The resonant frequency is

\[ f_{mn} = \frac{k_{mn} c}{2 \pi \sqrt{\varepsilon_r}} \quad \text{where} \quad (k_{mn})^2 = \left(\frac{m \pi}{a}\right)^2 + \left(\frac{n \pi}{b}\right)^2 \] (2)

To account for the fringing field at the perimeter of the patch effective length and width is to be calculated as explained in the chapter on theoretical investigations.

1.7.1 Magnetic current distribution

The electric field and magnetic surface current distributions on the sidewall for TM\(_{10}\), TM\(_{01}\), and TM\(_{20}\) modes are illustrated in Figure 1.9. For TM\(_{10}\) mode, the magnetic currents are constant and in phase along ‘b’ and out of phase along ‘a’. For this reason ‘b’ edge is known as radiating edge since it contributes predominantly to the radiation. For TM\(_{01}\) mode, ‘a’ is regarded as the radiating edge along which the magnetic currents are constant and in phase.

1.7.2 Radiation Pattern

The modes of general interest are TM\(_{10}\) and TM\(_{01}\) modes. These modes have broadside radiation patterns. The two are orthogonal to each other. TM\(_{10}\) and TM\(_{01}\) modes can be utilized to operate the rectangular patch as a dual frequency antenna also. Most of the other modes like TM\(_{11}\) have maxima off broadside.
Figure 1.9 Electric Field and magnetic surface current distributions in walls for different modes of a rectangular microstrip patch antenna
1.7.3 Directivity and gain

Directivity of $TM_{03}$ mode is largest and that of $TM_{10}$ mode the smallest. It is not sensitive to substrate thickness and permittivity. The gain on the other hand increases with resonant frequency.

1.8 SIMULATION TECHNIQUES

Electromagnetic Simulation is a new technology to yield high accuracy analysis and design of complicated microwave and RF printed circuit. IE3D is an integrated full wave electromagnetic simulation and optimization package for the analysis and design of three dimensional microstrip antennas. Its primary formulation is based on an integral equation obtained through the use of Green’s functions. The field and current distributions from the simulated structure are also accessible to the users using this package. FIDELITY is a finite difference time domain (FDTD) based full-wave electromagnetic simulator. Its basic principle is to use finite difference to represent the differentials in the Maxwells equations. The final algebraic equations for FDTD are in the time-marching style.

Through out the work presented in the thesis, the IE3D simulation results are used for optimizing the various antenna dimensions for a desired resonance frequency.

1.9 OUTLINE OF THE PRESENT WORK

The fast developments in the area of communication demands compact dual frequency microstrip antennas suitable for use in MMICs, satellite mobile communication, personal communication systems etc. In this thesis, theoretical and experimental investigations towards the development of a new compact dual frequency arrow shaped microstrip antenna are presented. The theoretical
investigations carried out resulted in the formulation of simple relations for calculating resonance frequencies, which made the analysis of the geometry easier.

Polarization diversity attained by changing the antenna dimensions is one of the important results obtained for these configurations. Various slot-loaded techniques for exciting new modes are explained with experimental and simulated results. Method for improving the bandwidth by cutting a pair of slots on the non-radiating edges is also presented in detail. Dual port geometry developed for arrow shaped antenna, which avoids cross talk between the frequencies of opposite polarizations is also discussed in this thesis.

1.10 CHAPTER ORGANISATION

In chapter 2, a brief review of the previous work in the area of microstrip antennas is presented with emphasis on compact microstrip antennas, broadband and dual frequency antennas.

In chapter 3, the methodology adopted for the development and analysis of the new patch antenna is presented. The fabrication techniques used in the antenna design is briefly explained. The facilities and techniques used for the measurement of different antenna characteristics like resonant frequency, return loss, radiation pattern, axial ratio etc. are also described.

The important observations and results of the experimental investigations carried out for the different antenna configurations are described in chapter 4. Chapter 5 explains in detail, the development of empirical relations for the design of this antenna. The resonance frequency calculations for single and dual port geometry are also included in this chapter.
The conclusions drawn from experimental and theoretical investigations are presented in chapter 6. Some possible applications of the newly developed antenna along with scope of further work are also described.

The work done by the author in related fields is incorporated as three appendices in this thesis. In Appendix A, dual frequency dual port crescent shaped microstrip antenna is presented. Appendix B discusses on compact circular sided microstrip antenna. Appendix C presents drum shaped antenna for dual frequency dual polarized operation and circular polarization.