Chapter 1

Introduction

1.1 Introduction to Antenna

Nowadays, wireless communications are taking up an important role in our everyday life and to create smaller and lighter mobile terminals is one of the critical requirements for the development of future wireless communications. Unlike electronic circuits, the size of an antenna is not technology-related, but is set by the laws of physics: the antennas size is restricted by the wavelength of a given application. This makes antenna miniaturization an art of compromise among antenna size, operating bandwidth and radiation performance. The parameters which best characterize the performance of a small antenna are the quality factor (Q), operating bandwidth and the Voltage Standing Wave Ratio (VSWR). The lower the quality factor, the more broadband the antenna; the lower the VSWR, the easier it is to transfer power from the transmission line to the antenna.

Currently there are several wireless systems applications in a multitude of areas such as mobile and personal communications, radio-frequency (RF) identification, wireless local area networks (WLAN), remote sensing, etc. Regardless of the application, most of those systems have similar demands for increased functionality, improved performance, compact size, and most importantly lower development cost. An objective that attracts a lot of effort is the integration of multiple functions on a single convergent system. Such a system requires a
one-step integrated solution for all sensing, computing, and communicating functions. An example could be a device, which can function as a cell phone, monitor weather, store data, perform basic computations, connect to the internet and can be hand-worn like a simple watch. Such devices require an effective packaging technique and a versatile transceiver that would be able to operate in different frequencies. An approach like that requires reconfigurable modules and therefore reconfigurable antennas.

Antennas are key components of any wireless communication system and it is a device that provides a way for radiation or receiving electromagnetic waves. IEEE standard definition of terms for antenna (IEEE Std 145-1983) defines antenna as a means for radiating or receiving radio wave [1]. Figure 1.1 shows an antenna as a conversion device. The arrows displayed in Figure 1.1 correspond to the electric field lines as the wave is transitioned into free space. The guided waves are transmitted by antenna into the free space may cover the short range or long range communication. Short range communications are Bluetooth, WLAN, Wi-Fi, PCS and etc and long range communications are Satellite communication, radar communication and Mobile communication and etc. When the antenna is used as receiver guided wave are received from the above said short and long range communications.

Wireless and mobile communication industry made a revolutionary remark in the 21st century with the development of modern communication equipment having ultra-compact size with multi features. The driving force behind wireless communication is the promise of portability, mobility and accessibility. The main problem of common antennas is that they only operate at one or two frequencies, restricting the number of bands that equipment is capable of supporting. Another issue is the size of a common antenna. Due to the very strict space that a handset has, setting up more than one antenna is very difficult. Therefore many kinds of miniaturization techniques, such as using high dielectric substrate, applying resistive or reactive loading and increasing the electrical length of the antenna by optimizing its shape with slots and meandering have been proposed by many Scientists. Similarly another technique is the application of reconfigurable geometry...
to conventional microstrip antenna (MSA) structure which optimizes the shape of the antenna in order to increase their electrical length and thus reduces the overall size, generating the multiple operating frequencies and enhancing the band width. In order to increase the capabilities of wireless integrated information systems and widen their bandwidths, the concept of reconfigurable antenna is presented. At present, the research of this realm is still at the beginnings throughout the world, and there are many unknown domains need to be explored. Thus the research on reconfigurable antennas is a challenging task. In this thesis, thorough research on reconfigurable antennas have been accomplished and several design schemes of reconfigurable antennas are presented. This work demonstrates great potential application prospects of reconfigurable antennas.

1.2 Types of Antenna

There are different types of antenna for different applications. Some of the common antennas are discussed in this section.
1.2.1 Wire Antenna

Wire Antennas are mainly used in cars and T.V where they are made of conducting wires. Therefore, the cost is usually low and fabrication is inexpensive. Wire antennas can include dipole, helical and Yagi-Uda. It usually operates at low frequencies and they have low gain [2].

1.2.2 Dipole Antenna

This dipole antenna was developed by Heinrich Rudolph Hertz [3] in the late 19th century. Dipole antennas are the most popular type of antenna. Dipole antennas consist of two metals wires with equal length. It can operate in the low frequencies. The evolution of a dipole is shown in Figure 1.2 and an example of a prototype of dipole antenna is shown in Figure 1.3.

![Figure 1.2: Evolution of dipole antenna.](image)

1.2.3 Monopole Antenna

In the early days, monopole antenna is shown in Figure 1.4 were the choice for mobile phone applications and they are still being used in countries that have limited coverage [2]. The advantages of monopole antennas when they are used in mobile phones are: (a) Low SAR (b) High efficiency.
Figure 1.3: Prototype of dipole antenna.

Figure 1.4: (a) Model of monopole antenna and (b) Prototype of monopole antenna.
1.2.4 Helical Antenna

The helical antenna, which is simply called helix. It is first introduced and investigated in 1950. In the 1990s, helical antennas were widely used in mobile handsets [4]. They have the advantage of wide band characteristic, circularly polarized radiation and adapting less space inside mobile phones [5] case as shown in Figure 1.5. Some mobile phone companies have stopped using this type of antenna in mobile phone because helical antenna is placed outside the handset, which can get broken easily by users.

![Helical Antenna Model](image)

Figure 1.5: (a) Model of Helix antenna (b) Helix antenna in Ericson mobile phone.

1.3 Microstrip Antenna (MSA)

In 1953, Deschamps G.A. was first proposed the concept of the microstrip antenna. However, practical microstrip antennas were developed by Munson and Howell in 1970 [6]-[8]. The numerous advantages of microstrip antenna, such as its low weight, small volume and ease of fabrication using printed-circuit technology led to the design of several configurations for various applications. With increasing requirements for personal and mobile communications, the demand for smaller and low profile antennas have brought the microstrip antenna (MSA) to the forefront. As shown in Figure 1.6 conventional Microstrip antenna consist
of a pair of parallel conducting layers separating a dielectric medium, referred as substrate. In this configuration, the upper conducting layer or "patch" is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conducting layer acts as a perfectly reflecting ground plane, bouncing energy back through the substrate and into free space. Physically the patch is a thin conductor that is an appreciable fraction of a wavelength in extent. The patch which has resonant behavior is responsible to achieve adequate bandwidth. Conventional patch designs yield few percent band widths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible.

![Figure 1.6: Patch Antenna.](image)

Since in 1970s microstrip antennas (MSA) have become very popular mainly for space borne applications [6] However, now they are being used for commercial applications as well. To meet different design requirements, the patch can take different forms of shapes, such as elliptical dipole, circular, triangle, rectangular and etc. as shown in Figure 1.7.

### 1.3.1 Advantages of microstrip antennas

MSAs have several advantages compared to other microwave antennas. Some of the principle advantages are as follows.
• Light weight and low volume.
• Low profile.
• planar configuration which can be easily made conformal to host surface.
• Low fabrication cost, hence can be manufactured in large quantities.
• Supports both liner as well as circular polarization.
• Can be easily integrated with microwave integrated circuits (MICs).
• Capable of dual and triple frequency operations.
• Mechanically robust when mounted on rigid surface.

1.3.2 Disadvantages of microstrip antennas
MSAs also have some disadvantages compared to conventional microwave antennas they are given below.
• Narrow impedance bandwidth nearly 1 to 2 percentages.
• Low efficiency.
• Low gain.
• Spurious radiation from feeds and junctions.
• Low power handling capacity.
• Surface wave excitation.
Table 1.1: Typical applications of Microstrip antennas.

<table>
<thead>
<tr>
<th>System</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft and ship antennas</td>
<td>Communication and navigation, altimeters</td>
</tr>
<tr>
<td>missiles</td>
<td>Radar and proximity fuses and telemetry</td>
</tr>
<tr>
<td>Satellite communication</td>
<td>Domestic direct broadcast TV, vehicle base band antenna, communication</td>
</tr>
<tr>
<td>Mobile radio</td>
<td>Pagers and hand telephones, mobile vehicle</td>
</tr>
<tr>
<td>Remote sensing</td>
<td>Large light weight aperture</td>
</tr>
<tr>
<td>biomedical</td>
<td>Applications in hyperthermia</td>
</tr>
<tr>
<td>others</td>
<td>Personnel communications</td>
</tr>
</tbody>
</table>

1.3.3 Applications of microstrip antenna

Even though the field of MSA may be considered to be in its infancy, there are many different successful applications with continuing research and development and with increased usage, it is expected that they will ultimately replace the conventional antennas for most applications. Some notable system applications for which MSA have been developed include satellite communication, Doppler and other radar, radio altimeter, command and control missile telemetry, weapon fusing, man pack equipment, environmental instrumentation and remote sensing, feed elements in complex antennas, satellite navigation receiver, biomedical radiator etc.

1.4 Introduction to Reconfigurable Antenna

The research presented in this thesis deals with different types of designed antenna for different wireless communications bands such as the Global System for Mobile Communications (GSM900 and GSM800), Personal Communication System (PCS1800 and PCS1900), Digital Communication Systems (DCS), Global Positioning System (GPS), Universal Mobile Telecommunications System (UMTS), Wireless Local Area Networks (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) etc. Some of these applications require fixed antenna where the antenna is designed and optimized to operate at particular frequency.
and some requires adaptive antenna (reconfigurable) where the antenna’s operating frequencies can change to other bands by using reconfigurable elements (multifunctional antenna). Different techniques have been used in the past to reduce the size of the antenna or to allow the antenna to operate in multiple band operations and also generate a wide bandwidth. Slots are usually employed in antenna’s structure and it has been widely used to achieve these techniques.

This section gives a brief overview of the latest techniques used to achieve multiple band antennas and to achieve a wide tunability range in reconfigurable antennas. Then the types of reconfigurability are discussed. To change the performances of the antenna electrically, tuning elements/switches such as chip capacitor, varactor diode and PIN diode have been used in order to tune/switch the operating frequencies or control the position of the radiation patterns or change the polarization of the antenna. (Extended electrical path length by using the varactor and pin diodes in antenna). Finally, modeling techniques and Zeland IE3D simulation software are discussed.

Now days antennas for mobile and wireless terminals supporting several standards simultaneously are currently receiving a lot of interest. Therefore, there is an increasing demand for multi-band antennas which can be easily integrated in a wireless device supporting multiple standards.

The different geometries are spiral antenna, simple bridge antenna, compact slotted antennas and multi-slotted antennas are the most suitable antennas to be used in wireless systems since they have low profile, low fabrication cost and adapt simple feeding structures.

These antennas are characterized by their length and width of the radiator shape, the height of the substrate above the ground plane and the dielectric constant of the substrate material. These antennas usually consist of radiated elements and a dielectric substrate material gloss epoxy on one side and a ground plane on the other.
Different techniques have been used in printed antennas to achieve wide band or multi-band operation. Some of these techniques are mentioned below.

- **Slotted radiators:** A cut on the patch elongates current path on the radiators and hence changes the performance parameters of the antenna. Hence slots technique is employed in the design of many antennas and it became the most commonly used technique [9]-[19].

- **Using foam layer between the radiator and the substrate can generate multi-band and wide band performance [20].**

- **Shorting wall:** the shorting wall allow the current to travel longer distance where in the bandwidth increases and the antenna size can be minimized [21].

- **Shorting pins:** shorting pins also improve the bandwidth of the antenna [22].

- **Stack multi-layers and fractal shape:** The fractal shape also can be used on the ground plane to generate multiple band operations [23,24].

The above techniques may result in larger dimensions and thickness of the physical antenna, which sometimes make it difficult to fit into small and electronic devices.

The size and the shape of the radiators, the height of the plate above the ground plane, the size, shape and position of the shorting plate or shorting pin, and the feed point location along the substrate all have considerable impact on the impedance matching, bandwidth, frequency bands, efficiency and gain of the designed antenna. The size of the radiator can be calculated by using below equation 1.1.

\[
\lambda = 4(L + W) \tag{1.1}
\]

Where, L is the length and W is the width of the radiating patch.
A reconfigurable antenna can be considered as one of the key elements in future wireless communication transceivers. The advantage of using a reconfigurable antenna is the ability to operate in multiple bands where in overall size to be reduced. Modern wireless communication systems relying on multi-band reconfigurable antennas are becoming more popular for their ability to serve ISM standards. Devices using a single compact antenna allow reduction in the dimensions of the device and more space to integrate other electronic components.

1.5 Types of reconfigurable antennas

Reconfigurable antennas can be classified into three different categories, namely, (a) Frequency reconfigurable. (b) Radiation pattern reconfigurable (c) Polarization reconfigurable

1.5.1 Frequency reconfigurable

The first category is based on frequency reconfigurability. The purpose is to tune/switch the operating frequency of the antenna and to have a single multi-functional antenna in a small terminal for many applications. The shape of the radiation patterns of these antennas remains unchanged when the frequencies are tuned/switched from one band to the other [25,26].

1.5.2 Radiation pattern reconfigurability

The second category is based on radiation pattern reconfigurability, where the frequency band remains unchanged while the radiation pattern changes based on system requirements. The antenna can steer its radiation pattern main beam in different directions. This type of pattern reconfigurability has been reported recently in [27] by using a CPW fed antenna. In, a reconfigurable antenna combining both frequency and radiation pattern reconfigurability was introduced.
1.5.3 Polarization reconfigurability

The third category is based on polarization reconfigurability, where the polarization is switched from linear to circular and from left hand circular polarization (LHCP) to right hand circular polarization (RHCP) as reported in. A novel reconfigurable patch antenna with both frequency and polarization diversity was also reported in.

1.5.4 Switching technology

The different switching technologies are used in reconfigurable antenna for generating multiple frequencies, bandwidth enhancement and for size reduction. The some of switching techniques are as follows.

1.5.5 PIN diode switches

PIN diode is a semiconductor device that operates as a variable resistor at RF and Microwave frequencies. It can also be used as a switch and limiter. PIN diodes are popular in microwave circuit applications due to its fast switching times and relatively high current handling capabilities[28,29]. The construction of a PIN diode is showing in Figure 1.8.

![Figure 1.8: PIN diode.](image)

The P and N types are separated by an intrinsic region, the P contact is the anode, and the N contact is the cathode as shown in Figure 1.9, where the anode is the side with the arrow, the cathode is the side with the plate. Between P and N region is the intrinsic where the width of this region has an important role on the performance of the PIN diode.
Figure 1.9: Symbol for PIN diode.

Figure 1.10 shows a simple equivalent circuit of a switch that can be ON or OFF. In the ON state, the switch can be represented as a resistor and a series capacitor in the OFF state.

![Equivalent circuit of a switch](image)

Figure 1.10: Simple switch equivalent circuit ON state and OFF state.

1.5.6 Varactor diode switches

Varactor diode also called varicap is a semiconductor diode with a small junction capacitance that varies its values depending on the bias voltage applied to the diode. They are important components of radio frequency or RF applications. Varactor diodes are widely used in communication applications when tuning is needed. The symbol for a varactor diode is shown in Figure 1.11.

![Varactor diode symbol](image)

The capacitance of a varactor decreases when the voltage gets reversed. A tuning varactor can be represented by the following electrical equivalent circuit as shown in Figure 1.12.
1.5.7 Microelectromechanical switches (MEMS)

MEMS switches are devices that use mechanical movement to achieve a short circuit or an open circuit in the RF transmission line. RF MEMS switches are the specific micromechanical switches that are designed to operate at RF-to-millimetre-wave frequencies.

In the last ten years, RF MEMS switches have been used for telecommunication applications due to many advantages compared to other switches such as small in size, good linearity and good isolation. However, they require high DC actuation voltages. MEMS switch are used in different applications such as phase array phase shifter, switching, reconfigurable networks and low power oscillator [30]-[33].

1.5.8 Modeling Techniques

Many methods have been developed over the past years for a wide range of applications in RF engineering. These methods or techniques can be divided
into: i) Time Domain (TD) such as Finite Different Time Domain (FDTD) and ii) Frequency Domain (FD) such as Moment of Methods (MOM) and Finite Element Method (FEM).

1.5.9 Moment of Method (MOM)

The Method of Moment (MoM) is a numerical method of solving electromagnetic problems or volume integral equation in the frequency domain. MoM can be used to solve problems in several areas of engineering and sciences including electromagnetic. In the 1960’s Roger F. Harrington was the first to use MoM to solve electromagnetic problem. Numerical Electromagnetic Code (NEC) is the most well known of the codes using MoM to solve problems that can be defined as sets of one or more wires. Although, it is an adaptable and thoroughly simple method, it requires large amounts of computation. The Method of Moments is broadly used to solve electromagnetic scattering and radiation problems. This technique is based on reducing the operator equations to a system of linear equations that is written in matrix form. The MoM applied to wire antennas for instance, is used by the commercial software IE3D. Results accuracy is considered an advantage using this method as it uses essentially exact equations and provides a direct numerical solution of these equations. Another advantage is that, in practice, it is applicable to geometrically complex scatters.

1.5.10 Finite-Difference Time-Domain (FDTD)

The Finite Difference Time Domain is a method that is broadly used to stimulate several electromagnetic problems. The literature on (FDTD) is extensive and has been used for various microwave analysis such as, antenna designs, propagation, filter design, and many other microwave analysis. However, FDTD is not suitable for electrically huge system but is good for system involving pulses. This method did not gain considerable attention despite its usefulness to handle electromagnetic problems until the computing costs became low. FDTD method was first proposed by Yee in 1966 for a simple Cartesian co-ordinate system. The FDTD algorithm iteratively calculates the field values in the problem space that is discretised into unit cells. Each unit cell is assigned with three orthogonal electric
and three orthogonal magnetic fields as shown in Figure 1.13.

![Figure 1.13: Yee cell.](image)

### 1.5.11 Finite Element Method (FEM)

The finite element method (FEM) is a mathematical technique used for finding approximate solutions of partial differential equations (PDE) as well as of integral equations. The solution is based on reducing the differential equation completely, or rendering the PDE into an approximating system of common differential equations, which are then numerically integrated using Euler’s method which is a standard technique such as the Runge-Kutta. FEM is a method used to solve frequency domain boundary valued electromagnetic problems using a variational form. There are generally two types of analysis that are used in FEM 2-D and 3-D canonical elements of differing shape. While 2-D conserves simplicity and allows itself to be run from a normal computer, it however, tends to give less accurate results. Three-dimensional canonical element, however, gives more accurate results by working effectively on faster computers. The FEM is often used in the frequency domain for computing the frequency field distribution in complex, closed regions such as cavities and waveguides [34]-[38].
1.5.12 IE3D solution formulation

The commercial moment method package IE3D [39] is the primary simulation tool used in this thesis for studying reconfigurable antennas. As with any package, care must be taken to ensure that the computed models reflect the actual behavior of the antenna. IE3D is a full-wave, frequency-domain simulation package that utilizes a laterally-open moment method engine capable of simulating arbitrary metallization geometries. Its primary formulation is an integral equation obtained through the use of Green’s functions. Both the electric current on metallic structures and the magnetic current representing field distributions on metallic apertures can be modeled. The solution to a general electromagnetic scattering problem, assuming a conducting Structure S in a dielectric environment, requires finding resulting current \( J(r) \) on S, induced by the incident field \( E_i(r) \). The induced field will create a secondary field to satisfy the boundary conditions on the surface. The induced field is distributed on the conducting surface and the boundary condition is given from,

\[
E(r) = Z_s(r)J(r) \quad (1.2)
\]

where \( E(r) \) is the total tangential field on S, \( J(r) \) is the current distribution on S, and \( Z_s(r) \) is the surface impedance of the conductor. IE3D uses a mixed potential integral equation (MPIE) based solution formulation. Thus it retains all vector and scalar components of the Green’s function in all calculations. This allows the placement of metal in arbitrary directions. The solver itself, however, is referred to as a 2.5 dimension solver while the field solutions depend on three spatial dimensions, the sources are concerned to planes with only two spatial dimensions and dielectrics must be layered and homogeneous. This results in a simplification of the problem space but comes at expense of problem generality. The resulting Green’s function formulation for 2.5D codes requires dielectrics to be infinite in lateral extent but of arbitrary height or thickness. This formulation makes 2.5D solvers particularly suited for planar geometries such as microstrip and multi-layer structures.
1.5.13 Modeling diodes in IE3D

Since it is difficult to model diodes, surface mount ceramic chip capacitors, inductors and resistors in a full-wave solver, the diode was modeled with a RLC boundary sheet.

**PIN diode:** The PIN diode can be modeled using RLC sheet. When the PIN diode is in the ON state, it acts as a resistance and if the PIN diode is in the OFF state, it acts as a capacitance. In the simulation, different modules can be created to check the results when switching the diode ON and OFF.

**Varactor diode:** Varactor diode is a variable capacitance. Depending on the capacitance range of the practical diode, the diode can be simulated with these values.

1.5.14 Reconfigurable antenna design

1.5.15 Basic characteristics

A frequency reconfigurable antenna is designed on glass epoxy substrate with a relative permittivity of 4.2 and the thickness of 1.6 mm, the microstrip in the design procedure, each segment could follow the outline of practical designs of rectangular microstrip antenna. The procedure assumes that the specified information includes the dielectric constant of the substrate, the resonant frequency \(f_r\) and the thickness of the substrate \(h\). The procedure is as follows.

**Determine: W, L.**

**Design procedure:**

1. The width of rectangular micro strip patch antenna is given by,

   \[
   W = \left[ \frac{C}{2f_r} \right] \left[ \frac{\epsilon_r + 1}{2} \right]^{-1/2}
   \]  
   (1.3)

2. Extension length (\(\Delta l\)): The extension length \(\Delta l\) is given by,

   \[
   \Delta l = 0.412h \left[ \frac{\epsilon_e + 0.3\left(\frac{W}{h} + 0.264\right)}{\epsilon_e - 0.258\left(\frac{W}{h} + 0.8\right)} \right]
   \]  
   (1.4)

3. Determine the effective dielectric constant of the microstrip antenna as
\[ \varepsilon_e = \left[ \frac{\varepsilon_r + 1}{2} \right] + \left[ \frac{\varepsilon_r - 1}{2} \right] \left[ \frac{1 + 12h}{W} \right]^{-1/2} \] (1.5)

Where, \( \varepsilon_e \) is the effective dielectric constant, \( W \) is width of patch and \( h \) is thickness of patch.

4. Elemental length (L):

\[ L = \frac{C}{2 \pi f \varepsilon_e - 1/2} - 2\Delta l \] (1.6)

Once the elemental width (W), extension length (\( \Delta l \)) and effective dielectric constant (\( \varepsilon_e \)) are determined using the above equations then the elemental length is found by using the equation,

1.6 Feeding methods

Once the patch dimensions L and W for a given substrate are found the next task is to determine the feed point so as to obtain a good impedance match between the generator and the antenna. There are many configurations that can be used to feed rectangular microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling and proximity coupling.

1.6.1 Microstrip line feed design

The microstrip line feed is designed by using the \( W/d \) ratio equation taking the known value of characteristic impedance \( Z_0 \) and dielectric constant of substrate material \( \varepsilon_r \). the design equation are,

\[ W/d = \frac{C}{2 \pi f \varepsilon_e} ; W/d < 2 \] (1.7)

\[ W/d = \left( \frac{2}{\pi} \right) \left[ B - 1 - I_n(B - 1) \right] + \left( \frac{\varepsilon_r - 1}{2 \varepsilon_r} \right) \left\{ I_n(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right\} ; W/d > 2 \] (1.8)
where

\[ A = \left( \frac{Z_0}{60} \right) \sqrt{\frac{\epsilon_r + 1}{2}} + \left[ \frac{\epsilon_r + 1}{\epsilon_r - 1} \right] \left[ 0.23 + \frac{0.11}{\epsilon_r} \right] \] (1.9)

and

\[ B = \left[ \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \right] \] (1.10)

The length of microstrip line is obtained from effective guide wavelength \( \lambda_g \). It is given by,

\[ \lambda_g = \left[ \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} \right] \] (1.11)

where

\[ \epsilon_{eff} = \epsilon_0 - \left[ \frac{\epsilon_r - \epsilon_e}{1 + G(f/f_p)} \right] \] (1.12)

\[ G = \left[ \frac{Z_0 - 5}{60} \right]^{-1/2} + 0.004Z_0 \] (1.13)

\[ f_p = \frac{Z_0}{2\mu_0 h} \] (1.14)

\[ \mu_0 = 4\pi \times 10^{-9} \] (1.15)

\[ \lambda_0 = \frac{C}{f_r} \] (1.16)

The length of microstrip line feed is taken as

\[ L_f = \frac{\lambda_0}{4} \] cm in order to keep minimum loss in microstrip line feed. If feed line is connected along the width of RMA, it will be connected usually at two points i.e. at the center and off-center point along the width of RMA. For the case of off-center point connection, it is necessary to find 50 \( \Omega \) impedance point along the width of RMA. The equation is used to calculate the 50 \( \Omega \) impedance point along the width is given by,

\[ R_{in} = \frac{(120\lambda_0)^2 + \left( \frac{377h}{\sqrt{\epsilon_r f}} \right)^2 (\tan^2 \beta l)}{240L\lambda_0(1 + \tan^2 \beta l)} \] (1.17)
Here $\beta l$ is assumed such that $R_{in} = 50\ \Omega$

In equation (1.17)

$$\beta = \frac{2\mu\sqrt{\epsilon_r}}{\lambda_0}$$

(1.18)

and

$$l = \frac{\theta\pi}{180\beta}$$

(1.19)

Hence, from equation (1.15) and (1.16) the microstrip line feed point (Wf) is identified and the microstrip line can be connected along the width starting from one edge of RMA as shown in Figure 1.14. If microstrip line is to be connected at the center point (W/2) along the width of rectangular microstrip antenna (RMA), it is necessary to calculate the impedance offered by the RMA at center point along its width using again equations (1.15) and (1.16). After calculating $R_{in}$ at the center point along its width of RMA, it is found that the impedance is not 50 $\Omega$. Therefore the microstrip line should not be connected directly to this center point of RMA as impedance mismatch occurs between the microstrip line and radiating element.

### 1.6.2 Coaxial feed

Coaxial feed is the one of feeding technique used to feed the probe to MSA which is shown in Figure 1.15. 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 the feed can be placed at any desired location inside the patch in order to match with its input impedance.

Figure 1.15 shows the probe fed rectangular microstrip patch antenna. This feeding method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled on the substrate and the connector protrudes outside the ground plane, thus it doe not make planar structure for thick substrates.
Figure 1.14: Patch antenna with microstrip feed line.
(h > 0.02λ₀). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems.

1.7 Motivation

The advent of wireless devices and mobile phone devices has revolutionized our life styles. Through the evolutionary process of development numerous of antennas have been developed for these applications. The requirements of new small and multi-band antennas are becoming even more challenging with time. To cope up with such challenging demands, a constant and even thorough research is required for developing new antennas capable of operating in multiple bands frequency applications. Moreover, from the literature survey it is observed that different feeding techniques are used for enhancement of gain and bandwidth at higher frequencies. But less work have been taking place in lower frequency towards size reduction with bandwidth enhancement. In view of above study has been made to design a frequency reconfigurable microstrip antenna which is suitable for wireless applications.
In this thesis, novel antennas are designed and developed to be used in re-configurable terminals for wireless applications to enhance the system capability. These novel antennas offer smaller size, slim and independently controlled bands, in addition to the added functionality in the performance of wireless systems.

1.8 Scope of the Thesis

The aims of the research presented in this thesis are mainly two folds: i) Design small and slim multiple bands antennas for wireless applications. The aim here is to make smaller antenna and to generate multiple bands from a single band antenna to reduce the size of wireless devices. Moreover, adding the independent control feature to allow the antenna to be designed to other applications easily. ii) Design of compact and slim reconfigurable multifunctional antennas for wireless applications. The aim here is to propose a tunable/switchable method to tune or switch between wide band and multi-narrow bands to be used for wireless applications. Moreover, proposed a new method through a switchable antenna that introduces multiple bands without the need to incorporate any additional parts and by only using a single varactor diode. Finally, introduce a tunable reconfigurable antenna with independently and simultaneously controlled multiple bands over a wide range to enhance the antenna capability in serving other standard. The research primarily focuses on achieving the following objectives:

1. In the first designs, using slots technique with different shape which can reduce the size of the antennas as well as allowing the antenna to generate multiple bands. The shape of the radiators or the slots must be simple and easy to optimize. To achieve independent control, the current distribution is an essential way to identify the key parameter for each band. Therefore, the bands should be obtained mainly from the main radiator not from the ground plane. Again, the current distribution on the structure must be mentor while designing and optimizing the antenna.

2. In the reconfigurable designs, studying the best location to place the switches in order to achieve a wide tuning range and independent bands over wide range. Slot must be used in order to disturb the current path on the an-
tenna and to allow the antenna to generate multiple band operations. Varactor diodes should be used to achieve fine tuning or PIN diode should be used to switch between the operating frequencies.

1.9 Organization of the thesis

This thesis consists of six chapters. The chapters are inter-dependent and the reader should follow the right order to better understand the contributions presented in the thesis. First Chapter-1 presents the introduction to antennas, different types of antenna, advantages and disadvantages of microstrip antenna also gives a brief introduction on reconfigurable antenna and general information about switching techniques i.e. PIN and varactor diodes is also provided. Chapter-2 gives an overview and some previous work in the area of reconfigurable microstrip antennas. This is followed by an introduction to modeling techniques used in simulations software and then giving a brief introduction to the chosen simulation software that was used to design and predict the performance of the antennas.

In chapter 3 the various microwave components and equipment used in the experimental setup, methodology and the block diagram of Vector Network Analyzer, its importance and measurement task, Zeland simulation software are described. Chapter-4 presents several antennas using switchable techniques. The first antenna is to be used in WLAN applications where the antenna can be switchable for multi-band operations. The next antenna introduces a new technique to select the number of bands (single, dual or tri bands) with some fine tuning capabilities. Wide tunable antennas using varactor diodes are introduced to cover the major wireless and other services and standards.

Chapter-5 presents results and discussion about obtained results of reconfigurable antenna. Various techniques like dual feeding, putting slots on the patch and situating the switching elements on the slot in order to enhance the bandwidth and good size reduction. The various parameters like frequency reduction, return loss, bandwidth and radiation characteristics etc are also reported. Finally, Chapter-6 concludes the research findings of the thesis and presents the future work to be carried out.
The thesis ends with the list of author’s publications which are published in leading International journals and one in National conference.