DESIGN OF SPECIFIC ULTRA WIDE BAND ANTENNA FOR SATELLITE COMMUNICATION

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Submitted

IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

To

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

DEHRADUN

January 2016

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **"Design of Specific Ultra Wide Band Antenna for Satellite Communication"** by **Ranjan Mishra** in Partial completion of the requirements for the award of the Degree of **Doctor of Philosophy** (Engineering) is an original work carried out by him under our joint supervision and guidance.It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

Guide

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DECLARATION

I do hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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सर्व्यापी भगवान

हम भगवन के हैं और भगवन ही हमारे हैं

ACKNOWLEDGEMENT

At the outset let me express my gratitude towards the All Mighty for giving me the motivation and hope to present this work.

Let me express my heartfelt gratitude towards the Chancellor and Vice Chancellor who gave their kind consent to carry on this work and providing support throughout this work.

Let me thank the Dean, Dr. Kamal Bansal, for his constant guidance and help for a complacent of the current work.

The constant beacon of light and the edifice of the work has been Dr. Piyush Kuchhal and any amount of gratitude would fall short for the kind of contribution towards making of the work. The source of the idea and the implementation would not take its current shape without his guidance. He has been a great source motivation, friendliness throughout the work.

Let me thank Dr. Adesh Kumar for his constant motivation and help.

I would be failing in my duties if I don't thank my friend Raj Gaurav Mishra for his help and support. I also thank all my friends, especially Tarun Kumar and Narendra Soni, who lent constant motivation and support.

I would be very much thankful to Dr. Parag Divan, the Ex-Vice Chancellor, for his kindness and support.

The greatest sense of acknowledgement would go to my family members who have been in the roots of whatever I am and have achieved my life including this work.

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List of Symbols

A_e : Effective Aperture

B : Channel Bandwidth

c : Velocity of Electro-Magnetic Wave

C : Channel Capacity

D : Directivity

ΔL : Length Correction factor

E : Electric Field Component

E_t : Total Efficiency

E_r : Radiation Efficiency

ϵ_r : Permittivity or Dielectric Constant

ϵ_{eff} : Effective Permittivity or Dielectric Constant

f : Frequency of Electro-Magnetic Wave

G : Gain

h : Height of Substrate

H : Magnetic Field Component

l_e : Loss Tangent

λ : Resonant Wavelength of Electro-Magnetic wave

L : Length of Rectangular Microstrip Patch Antenna

L_m : Length of Microstrip Feed Line

L_s : Length of the Slot

L_G : Length of Substrate

μ : Permeability

η : Efficiency

P : Power

p : Distance of Slot form Non-Radiating Edge

ϕ : Azimuth angle

Q : Quality Factor

S : Radiated Power Density

S_{11} : S-Parameter or Return Loss

σ : Thermal conductivity

t : Thickness of the Patch

τ : Reflection coefficient

θ : Elevation angle

U : Radiation Intensity

W : Width of Rectangular Microstrip Patch Antenna

W_m : Width of Microstrip Feed Line

W_s : Width of the Slot

W_G : Width of Substrate

Y_{in} : Input Admittance

Z_c : Characteristic Impedance

Z_{in} : Input Impedance

Executive Summary

Ultra Wide Band usually denotes to signals or systems having a large relative or a large absolute bandwidth. This large bandwidth provides a precise improvement in signal robustness and information content. This also deluges the high data rate transmission. The previous decade endures a confluence of technological, economic and political covenant that empowered the usage of Ultra Wide Band systems. The development and utility of Ultra Wide Band technology demands more acceleration in antenna design. The design aspect of achieving the Ultra Wide Band is more challenging due to the requirement of a high fractional bandwidth of more than 25% in the Ultra Wide Band range that covers 3.1 GHz to 10.6 GHz. It also requires the antenna to have a uniform satisfactory characteristic over the entire operational frequency.

Antenna is the mainstay of the wireless communication. The evolution of Microstrip antennas came into existence in the last quarter of the twentieth century, but the research and development in the field of microstrip antenna engineering has been accelerated much to other types of antennas. Flexibility, low weight, manufacturing ease, integrated with microwave integrated circuits of these antennas has many utilities in various wireless communication systems. The salient features of these antennas motivate researchers to improve its capabilities. The increasing demand of high data rate and reduction in size of the device in the various applications of the modern wireless communication systems accelerated the design issue for microstrip antenna. A compact antenna structure and high bandwidth are the constraint for research in the practical antennas. An array of these antennas delivers the desired high gain. The less bandwidth of this antenna hinders its progress, but the appreciable effort of the researchers overcomes this shortcoming. The quest of high bandwidth and better performance would continue to be a driving force in forwarding this antenna as a thriving technology for years to come.

This thesis focuses on designing a specific, simple and compact rectangular microstrip Ultra Wide Band antenna having optimum performance like very high and wide bandwidth, good matching impedance, double resonant peak with high return loss, minimum voltage standing wave ratio performance and high radiation efficiency. The essential parameters of the rectangular microstrip antenna are discussed and the various means are exploited for enhancing its bandwidth so that the test antenna would reveal excellent performance and meet the Ultra Wide Band specification.

Further the design of the test antennas are fabricated by coordinatograph method and tested with vector network analyzer to validate the designs. The corroboration of the design is also done by comparing the tested result with the theoretical model at least in one case. Finally the comparison is made with the results of the others to propose the best design and the recommendation are made for the future work.

Thesis Organization

The main challenge in microstrip patch antenna is to achieve wide bandwidth. The microstrip antenna in original form possesses narrow bandwidth and resonates at a single frequency. The present work is carried out to design and develop the microstrip patch antenna operating in the Ultra Wide Band range of frequency. the entire work is organized in terms of six chapters.

The **First chapter** presented an introduction of the Microstrip antennas and the Ultra Wide Band systems. The features, advantages, limitations and the different types of feeding techniques are also discussed. The methods for the modelling of the microstrip antenna are also conversed. A brief review on the software used in the designing of the desired antenna is also cited. It also presents a brief time-line of the antenna development, along with the basic categories of the antenna. Salient parameters describing the characteristic of the antenna are also discussed. A brief review on the satellite communication is presented along with the motivation and objectives of the work.

The **Second chapter** contains the various literature reviews. Since the aim of the work is the designing of the Ultra Wide Band antenna, hence the various planer methods in the designing of microstrip antennas are presented in this chapter. It contains the review of the latest works done.

The **Third chapter** is the essence of the work. It is related to the main design of the specific antenna including all the basic design process. A patch antenna has a narrow bandwidth in general. The chapter focuses on the various means for the broadening of the antenna. The effect of various parameters of the patch in achieving the broad bandwidth is discussed in detail. In this chapter the effect of height of substrate, the width of patch and the dimension of the feed line on the bandwidth is analyzed. Also the broadening of the antenna using the suitable slots, notches and partial ground plane are also presented. In the designing of the desired antenna both the antenna design software viz. ADS version 9 and HFSS version 12 are also presented in this chapter. In the end three different specified antenna configurations are also presented.

The **Fourth chapter** deals with the fabrication of the proposed antenna and the measurement of its characteristics. The various fabrication methods such as chemical etching, photo lithography and coordinatograph are discussed in this chapter. A brief introduction to the various types of network analyzer is also presented with a more insight into the vector network analyzer. All the three proposed antennas are fabricated by coordinatograph method and their characteristics are measured by vector network analyzer.

The **Fifth chapter** is dedicated to validation of the work presented. In this chapter, comparisons between the simulated results and the measured results of the antenna hardware are presented. The various passive parameters taken for the comparisons are return loss, voltage standing wave ratio, through power. The results obtained from the simulated and measured results of these parameters are compared and discussed in this chapter. The simulated results of the active parameters such as gain, directivity, radiation efficiency and radiation pattern are also specified here. In this chapter the comparison of the theoretical bandwidth and the measured bandwidth of the antenna is also presented by the analysis using the cavity model. The help of transmission line model is also taken in comparing the theoretical and measured impedance of the antenna.

The **Sixth chapter** has a concluding note about the work along with the future scope. At the end of this thesis a detailed relevant bibliography is reported that deals with the reported work in the area of microstrip antenna and Ultra Wide Band systems.

Chapter 1

Introduction

Radio is a magic.

"Rays of light will neither pierce through a wall nor too well through London fog. But the electrical vibrations of a yard or more in wavelength will easily pierce such mediums. Here then, is revealed the bewildering possibility of telegraphy without wires, posts, cables or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment." `William Crookes - 1892`

The magic and mystery of Radio waves have captured imaginations from the earliest speculations of William Crookes [1] to the present day. The marvel of Radio is taken for granted in the world of pervasive and instantaneous wireless communications. All around us quiver vibrations in the conveying voices, images, data and information. The magic of radio plucks these vibrations out of air and recovers the original data. The wand responsible for this wizardry is the antenna. An antenna makes a Radio wireless device possible. A transmit antenna takes signal from a transmission line, converts them into electromagnetic waves, and broadcasts them into free space. On the other end of the link, a receive antenna collects the incident electromagnetic waves and converts them back to the signals.

James Clarke Maxwell first laid out his remarkable equations that describe the behaviour of the electric and magnetic fields in 1865. The journey from Maxwell equation to understand electromagnetic radiation and radio waves took a long twenty years and many debates. The existence of the electromagnetism resolved with the Henrich Hertz experiment and demonstration of it in 1884. Hertz led the way as the first to generate radio waves and subject them to scientific scrutiny.

A great many innovators like Nikola Tesla, Carl Barun, Alexander Popov and Reginald Fessenden contributed key elements to radio technology. The other forefront pioneers are Oliver Lodge, Jagdish Chandra Bose and Guglielmo Marconi. Lodge invented the biconicals and introduced the concept of transmitting and receiving usinga particular frequency and tuned circuits. Bose performed pioneer work in millimetre wave systems and invent horn antenna. But it was the remarkable work of Marconi that open the path of radio communication. Marconi first commercialized radio as a means of long range communication. The fundamental works of these great open the gateway of antenna technology [2] and it require decades of technical development to full realization of Crookes's vision.

The frontiers of radio science surge past high frequency range beyond the speech, and a new generation of antenna design come forward to tackle the problem of creating broadband. As frequencies used in radio spectrum increased and wavelengths become shorter, high performance broadband antenna grew. Shorter wavelength made complicated antenna elements more practical. Not only were frequencies going high but also bandwidths were become wide. The discovery of Frequency Modulation by Edwin Howard Armstrong in 1933 demands a twenty times more bandwidth than the first radio broadcasting by Amplitude Modulation. The advent and rise of television also led to a demand for antennas that could handle much wider bandwidths of the order of 7 MHz. The renewed demand for wideband antennas led to Philip Carter's rediscovery of the biconicals antenna and Nils Lindenbald's coaxial horn element in late 1940s.

Improvement in radio electronics led to higher and higher frequencies and the fuelled the demand for broadband antennas. Moving further in response to advances in radio technology led to the development of Ultra Wide Band antenna [3]. A time line of the major development in antenna upto Ultra Wide Band [4] is summarized in Table 1.1.

1.1 Types of Antenna

An antenna can be classified in number of ways [5]. The simplest of the antenna configuration is the wire antenna. This oldest structure is regarded as the simpler and cheaper. It is also the most versatile antenna for many applications.

1.1.1 Classification in Terms of Wire Structure

In wire antenna there are three further classification.

i. **Dipole** or **Linear Wire Antenna** - An antenna in the form of straight wire is termed as dipole or linear wire antennas.

ii. **Loop Antenna** - An antenna where the single wire is used to form a loop it is termed as loop antenna. The loop can take any form, but generally circular and square loop is mostly used for the ease of analysis and construction.

iii. **Helical Antenna** - An antenna where the wire is bend in an helical shape. It is also termed as helix antenna.

1.1.2 Classification in Terms of Aperture

One more classification is based on the aperture antenna, where the surface is a two dimensional one. The different antenna comes under it are as follows:

i. **Horn Antenna** - An antenna constructed from the waveguides are termed as horn antenna. A waveguide is a hollow metallic tube used. The shape of the horn antenna depends on the cross section of this waveguide through which the waves propagates. When one end of the waveguide is trapped to a large opening and its acts as an antenna. The shape of the antenna is either rectangular or circular in shape.

ii. **Parabolic Disc Antenna** - An antenna having a shape of parabolic or disc shape. It is mostly used for very long distance reception or space reception. They are also termed as reflector antenna.

iii. **Microstrip Antenna** - An antenna having radiating patch etched on the substrate. The other side of the substrate is a metallic ground plane.

iv. **Array Antenna** - An antenna formed by multi elements. They are used at times when a single element is unable to give the desired features. The desired features can be achieved by using multi-element in the antenna structure.

1.1.3 Classification in Terms of Frequency

An antenna is also classified in terms of frequency, aperture, polarization and radiation. Out of these classes the frequency is the most important one. Therefore in term of frequency specific class, the antenna classification is as follow:

i. **Very High Frequency (VHF)** & **Ultra High Frequency (UHF) Antennas**: Yagi-Uda antennas, log periodic antennas, Helical antennas, Panel antennas, Corner reflector antennas, parabolic antennas, discone antennas are some of the antenna who are operating in this frequency. the range of VHF is from 30 MHz to 300 MHz, and that of UHF is from 300 MHz to 3 GHz.

ii. **Super High Frequency (SHF)** & **Extremely High Frequency (EHF) Antennas**: In this range the frequency is in excess of 3 GHz. They are also called microwave antenna. The different antenna covers are parabolic antenna, pyramidal horn antennas, discone antennas, monopoles and dipoles antennas, Microstrip patch antennas, fractal antennas.

Year	**Developments**
1865	Maxwell's equations formulated
1885	Poynting Heaviside theory
1887	Hertz discovered radio waves
1892	Crookes speculates about radio communication
1895	Marconi demonstrated radio system with square plate antenna
1896	Lodge proposes synotic radio with biconicals and bow ties
1897	Bose demonstrates mm-wave apparatus, including horn antenna
1901	Marconi claims trans-Atlantic signal
1912	Titanic signals for help using wireless
1920	Commercial AM broadcasting begins
1939	Carter rediscovers biconicals, invents feeds, alpine horn
1940	Lindenblad develops TV antenna
1941	Schelkunoff invents spherical antenna
1941	King rediscovers conical horn
1945	Kraus invents corner reflector
1946	Katzin rediscovers pyramidal horns
1946	Kandoian invents discone
1948	Brillouin designs coaxial horns
1949	Masters invents diamond dipole
1952	Schelkunoff and Friss present teardrop biconicals, tapered slots
1957	Rumsey introduces frequency independent antenna
1958	Lamberty describes square plate monopole
1961	Turner and Turner design scimitar antenna
1962	Marie invents a stepped slot antenna
1968	Stohr develops ellipsoidal antenna
1974	Lee proposes ellipsoidal antenna
1982	Burnside and Chuang rolled edge horn
1984	Harmuth introduces the LCR antenna
1985	Nester invents a microstrip notch horn
1989	Lalezari et al, invent a dual notch antenna
1992	Honda et al, describe a circular monopole
1992	Snyder and Peisley invent a rolled edge discone
1994	Thomas et al, invent circle dipoles
2002	Federal Communications Commission approves Ultra Wide Band

Table 1.1: Time Line of the Major Development in Antennas

1.2 Antenna Characteristics

An antenna makes a radio frequency communication device possible. On the transmission side, it takes electrical signal from a transmission line, converts into electromagnetic waves, and finally transmits into free space. On the receiving end, it collects the incident electromagnetic waves and converts back into the electrical signal. The characteristics of an antenna is usually done on the basis of different parameters [6]. These parameters are defined on the basis of electromagnetic field radiated by the antenna. Knowing the radiated fields, the radiation pattern of the antenna is obtained and from it the various properties are quantified.

Antenna must undergo with various measurements. There are two types of measurement. One is passive measurement and another is active measurement. Passive measurement involves return loss, voltage standing wave ratio (VSWR) and impedance bandwidth. Active measurement includes the radiation pattern, gain, efficiency and directivity of the antenna parameters. The fundamental and important parameters for the antenna are listed below:

1.2.1 Radiation Pattern

It is the angular distribution of the power radiated in the free space by an antenna. It defines the variation of the power radiated by an antenna as the radio signal leaves away from the antenna. The radiation pattern of any antenna determines its coverage area in free space.

1.2.2 S-Parameter

S-parameters describe the input to output relationship between the two ports or two terminals of the system. S-parameters are exclusively the function of frequency and it varies with the frequency. In a general system if two ports are represented by port A and port B, then the power transferred from port B to port A is describe as S_{AB}.

S_{11}, better known as return loss or reflection coefficient, is then defined as the reflected power in the port as it delivers the power to the antenna. S_{11} is a measure of the power is reflected back at the antenna due to mismatch from the transmission line. For a S_{11} value of 0 dB all the power are reflected back by the antenna. More is the negative value of S_{11} better will be the antenna performance. Most of the antennas are designed to be low loss; therefore the majority of the power delivered to it is radiated into the free space.
The reflection coefficient is the ratio of the transmitted voltage to the reflected voltage. Therefore the return loss or the power fraction reflected (S_{11}) is proportional to the reflection coefficient squared.

$$\text{Return loss (dB)} = 20\ \log|S_{11}| = 20\ \log|\Gamma| = 10\ \log|\Gamma|^2. \qquad (1.1)$$

1.2.3 VSWR

This parameter numerically describes how good a particular is matched with the transmission line connected to the antenna. For a transmitter, the impedance of it must be well matched to the impedance of the antenna. It value varies from 1 to infinity. The smaller the value better is the matching of antenna with the input line and more is the power delivered to the antenna by the line. For a VSWR of value 1, all the power is radiated and no power is reflected back.

VSWR is frequently used parameter to characterize the impedance matching. It is defined as the ratio of the peak voltage maximum to peak voltage minimum in the standing wave pattern at an impedance discontinuity. This is also regarded as the variation in the amplitude of the standing wave envelope. For a perfect matching, there is no reflected signal and VSWR becomes 1. VSWR is related to the reflection coefficient as:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{1.2}$$

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \tag{1.3}$$

here, Z_{in} and Z_o are the input and normalized impedance of the terminal. And, the return loss, $R_L = -20log\Gamma$.

1.2.4 Bandwidth

It is the fundamental and desired determining parameter of the antenna. It describes the range of frequencies over which an antenna radiates or receives electromagnetic energy in order to maintain a defined return loss. It is also referred as the impedance bandwidth. Since the impedance of an antenna varies with the frequency, the antenna is matched with the line within a limited range of frequencies. This range of the frequencies defined the bandwidth of the antenna. The bandwidth is paired with a Return Loss or VSWR value.

A UWB antenna is distinguished by its large bandwidth. Thus bandwidth is an important appropriate place to begin an examination of a UWB antenna's properties. Bandwidth is simply the difference between the operating upper frequency, f_H and lower frequency, f_L.

$$BW = f_H - f_L \tag{1.4}$$

From an antenna point of interpretation, the upper frequency and the lower frequency are the frequencies agreeing to a return loss of -10 dB. A typical diagram in Figure 1.1 shows the return loss (or S_{11} parameter) of a typical antenna. It also shows that the upper frequency and the lower frequency are 10.45 GHz and 2.80 GHz respectively. Consequently the bandwidth is 7.75 GHz.

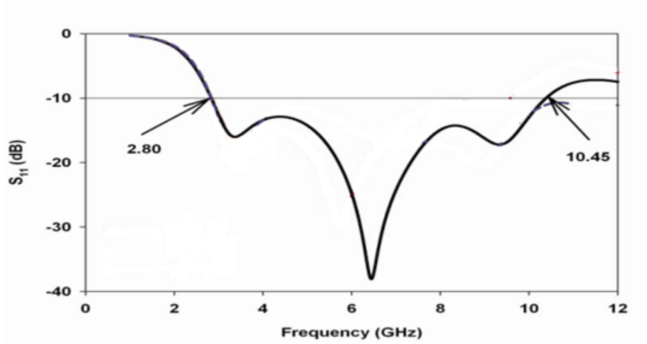

Figure 1.1: Calculation of Bandwidth by Return Loss (S_{11}) Plot of a Typical Antenna

The fractional bandwidth (BW) of a system is the ratio of bandwidth to the center frequency. The fractional bandwidth in percentage (BW%) is defined as:

$$BW\% = 2\frac{BW}{f_H + f_L} \text{ x } 100 \tag{1.5}$$

$$BW\% = 2\frac{f_H - f_L}{f_H + f_L} \text{ x } 100 \tag{1.6}$$

1.2.5 Antenna Pattern

An antenna pattern is a measure of view of an antenna. It describes the spatial distribution of energy radiated or received by the antenna. The broad opinion is that of an isotropic antenna. More practical is omnidirectional antenna though for some purposes directional antenna is preferred. An examination of the orientation and arrangement of the antenna elements reveals the orientation of the electric fields.

Isotropic antenna is the one which radiates and receives energy uniformly in all directions. A true isotropic antenna is a topological impossible because electromagnetic waves are transverse in nature.

An omnidirectional or omni antenna radiates and receives energy uniformly in all azimuthal directions. An omni pattern may be readily achieved. They confined the energy in a particular plane. Dipole and small loop antenna are the examples of omni antenna. Cell phones typically employ an omni direction pattern. This pattern allows the device to remain connected with cell tower and other devices lying anywhere in the same general plane.

Directional or gain antennas focus energy in a particular narrow field of view. It is ideal for a point to point link or any other application where the antenna is aligned to aim directly at the other end of the link. Horn antenna, disc antenna and reflectors are the typical example of it.

An antenna pattern function, P(θ,ϕ), describes the angular distribution of the energy radiated or received by the antenna. The half-power or -3 dB, points define an antenna's field of view. The half power bandwidth of an antenna is defined as the angular measure between the -3 dB points.

The pattern of the antenna describes how well an antenna directs or focuses energy in a particular direction. As an antenna directs more and more energy into a smaller field of view, the signals it receives or radiates become larger and larger. The signal enhancement relative to an isotropic antenna signal is referred as gain. Gain is directly proportional to directivity. The proportionality constant is termed as antenna efficiency. The aperture of the antenna describes its ability to intercept a portion of an incident electromagnetic wave.

1.2.6 Gain

Gain describes the amount of power transmitted in the direction of peak radiation with respect to the power transmitted by an isotropic source. An antenna of gain 3 dB defines that the power received from this antenna would be 3 dB higher than received from a lossless isotropic antenna having the same input power. Gain is also defined as the ratio between maximum radiation intensity to the total input power.

$$G = \frac{\text{maximum radiation intensity}}{\text{total input power}} = \frac{4\pi|U(\theta,\phi)|_{max}}{P_{in}} \tag{1.7}$$

In terms of efficiency of the antenna,

$$Gain = \frac{4\pi|U(\theta,\phi)|_{max}}{P_{in}} = \frac{E_r 4\pi|U(\theta,\phi)|_{max}}{P_{rad}} = \frac{E_r}{D} \tag{1.8}$$

Gain (in dB) = G_{dB} = 10 log G. An ideal isotropic antenna ($\eta \approx 1$) has a gain of 0 dB. Here the transmitted power is uniformly distributed over the area of a spherical shell at a particular range (R) from the antenna. Thus, the radiated power density (S) is given as:

$$S = \frac{P_t G_t}{4\pi R^2} \tag{1.9}$$

Here P_t and G_t are the transmitted power and transmitted antenna's maximum gain.

Finally, the Effective Isotropic Radiated Power (EIRP) is defined as:

$$EIRP = P_t G_t \tag{1.10}$$

The Effective Aperture (Ae) of the antenna is its effective capture area. It is the area of an incident wave front that the antenna can be intercept. It is defined in terms of gain and wavelength.

$$Ae = \frac{G\lambda^2}{4\pi} \tag{1.11}$$

The aperture of an isotropic antenna is equivalent to a disk of radius $\lambda/2\pi$.

1.2.7 Directivity

Directivity is the ability of antenna to focus radiation. This term describes the measurement of the directional property [7] of it. It is applicable only to the directional properties of the antenna and is controlled by the radiation pattern. The directivity of an antenna is 1 if it radiates equally and uniformly in all directions. It has effectively zero directionality.

The Directivity (D) of the antenna is the ratio of how much energy it directs in a particular direction divided by the average energy. The directivity of an isotropic antenna is 1.

$$D = \frac{\text{Peak Energy}}{\text{Average Energy}} = \frac{|P(\theta,\phi)|_{max}}{\frac{1}{4\pi}\oint |P(\theta,\phi)| sin\theta \text{ x } d\theta \text{ x } d\phi} \tag{1.12}$$

Directivity and gain are related to efficiency (η). Efficiency is the ratio of the radiated power and the input power.

$$\eta = \frac{P_{rad}}{P_{in}} = \frac{Gain}{Directivity} \tag{1.13}$$

Gain and directivity are intimately connected. For an ideal or high efficient antenna ($\eta \approx 1$) the gain is identical to the directivity. Gain is usually expressed relative to the gain of an isotropic antenna in units of decibels.

The difference between gain and directivity is the concepts of defining the power describe mathematically. For a lossless antenna, gain is equal to directivity since the input power delivered to it is same as the output power radiated away from the antenna. i.e. $P_{rad} = P_{in}$. Therefore, in this case gain is equal to directivity.

1.2.8 Antenna Efficiency

It is the ability of an antenna to transmit input power into the radiation. It relates the power delivered to the antenna with the dissipated within the antenna. It shows how well an antenna transmits the accepted input power to the output radiated power. An antenna with high efficiency has most of the power being radiated into free space, whereas a low efficiency has most of the power being absorbed or reflected away due to impedance mismatch. The antenna efficiency is defined as the ratio of the radiated power to the input power. It also relates the gain of the antenna with its directivity. An efficient antenna transmits most of its power into the free space as radio waves.

$$\text{Radiation Efficiency} = \frac{\text{Power Radiated}}{\text{Power Input}} = \frac{\text{Gain}}{\text{Directivity}} \tag{1.14}$$

Total efficiency is the radiation efficiency of the antenna multiplied by the impedance mismatch loss of it. Since the impedance mismatch loss varies from 0 to 1, the total efficiency is always less than the radiation efficiency. For a perfect matching, the two efficiency are same.

$$E_t = M_L \text{ x } E_r \tag{1.15}$$

where, E_t is the antenna's total efficiency, M_L is the mismatch loss and E_r is the antenna's radiation efficiency.

Efficiency is defined as the ratio of radiated power (P_{rad}) to input power for an antenna (P_{in}).

$$\eta = \frac{P_{rad}}{P_{in}} \tag{1.16}$$

Input power is the net power accepted by the antenna at its terminal during the radiation process. There is no distinction between the applied power at the antenna terminals and the accepted power at the antenna terminals. Any accepted power is either radiated away or consumes in ohmic loss or dielectric loss. If taking into the mismatching loss from the antenna, the input power is expressed as:

$$P_{in} = P_{applied} = P_{accepted} + P_{reflected} = P_{rad} + P_{loss} + P_{reflected} \tag{1.17}$$

Thus a better evaluation of the efficiency is:

$$\eta = \frac{P_{rad}}{P_{in}} = \frac{P_{rad}}{P_{reflected} + P_{rad} + P_{loss}} \tag{1.18}$$

1.2.9 Impedance of an Antenna

Antenna impedance is an important parameter. The antenna impedance is the ratio of voltage to the current and is expressed in ohm. To transfer the maximum amount of power from a microwave source to the load or the antenna, the impedance of the load or the antenna should match that of the impedance of the source. An improper matching will led to a loss in the power and degrade the performance of the antenna. The impedance of antenna is represented by the power that is absorbed by the antenna and the power dispersed by it. As the electromagnetic wave travel through different parts of the antenna system they are encounter with different impedance at the junction of each interface. Generally the waves travel from source to feed line to antenna and then radiated into free spaces. At each interface the waves encounter with mismatch impedance and this results in the reflection of some of the waves backward. This generates a standing wave in transmission line. A proper impedance matching reduces the standing wave and improves the performance.

Table 1.2 shows typical value of VSWR, Return loss, through power and power loss for a range of antenna matches [4].

Match	**VSWR**	**Return Loss (dB)**	**Through Power (%)**	**Power loss (dB)**
Marginal	3.00:1	-6.0	25.0	-1.250
Good	2.00:1	-9.5	88.9	-0.511
Very Good	1.92:1	-10.0	90.0	-0.458
Excellent	1.50:1	-14.0	96.0	-0.177
Superb	1.22:1	-20.0	99.0	-0.443

Table 1.2: Matching in terms of VSWR, Return loss, Through Power and Power loss

1.3 Microstrip Antenna

Microstrip antenna (also known as a patch antenna) is one of the latest technologies in antennas and electromagnetic applications. It is widely used nowadays in the wireless communication system due to its simplicity and compatibility with printed circuit technology. Microstrip geometries which radiate electromagnetic waves were originally contemplated in the 1950s. The concept of microstrip antenna was first proposed by Deschamps [8] in the year 1953. Gutton and Baissinot presented a patent in on the microstrip in the year 1955.

Early microstrip lines and radiators were specialized devices developed in laboratories. No commercially available printed circuit boards with controlled dielectric constants were developed during this period. So this antenna didn't become practical till 1970s when it was developed further by Robert E. Munson [9, 10].

Development during this decade was accelerated by other researchers by the availability of low-loss tangent substrate materials. Others factors for the development includes improved photo-lithographic techniques, better theoretical modelling and attractive thermal and mechanical properties of the substrate. The first practical antenna was developed by Munson [11] and Howell [12]. Since then extensive research and development of microstrip antennas and their arrays have led to diversified application within the broad field of microwave antennas.

Microstrip or printed patch antennas are used in almost all wireless systems with recent advancements in printed circuit technology. The purpose of microstrip or patch antenna is to radiate and receive electromagnetic energy in microwave range and it plays an important role in wireless communication applications. The performance and operation of a microstrip antenna is dependent on the geometry of the printed patch [13] and the material characteristics of the substrate onto which the antenna is printed.

1.3.1 Characteristics of Microstrip Antenna

The Microstrip antenna has proved to be an excellent radiator for many applications because of its several advantages [14] as compared to conventional microwave antennas. This results its many applications over the broad frequency range from around 100 MHz to 100 GHz. Some of the principal advantages are:

i. They are light in weight.

ii. They occupy low volume.

iii. They are of low profile planer configuration.

iv. They can be made conformal to planar and non-planar surfaces.

v. Their ease of mass production leads to a low fabrication cost.

vi. They are easy to implement on the device.

vii. They are easier to integrate with other MICs on the same substrate.

viii. They allow both linear polarization and circular polarization with simple feed.

ix. They can be made compact for use in personal mobile communication.

x. They allow for dual- and triple-frequency operations.

xi. They act as an efficient radiator.

xii. They have low scattering cross section.

xiii. They are mechanically robust when mounted on rigid surfaces.

xiv. They are Resistant to shock and vibration.

xv. They are well Compatible for embedded antennas in handheld wireless devices.

xvi. The feed line can be easily fabricated at the same time on the substrate.

However, these antennas also have some limitations as compared to conventional ones. These are:

i. They have narrow bandwidth.

ii. The efficiency is low.

iii. They have low gain.

iv. They have low power handling capacity.

v. They have low isolation between radiating elements and feed.

vi. Complex feed structure required for high performance arrays.

vii. Large ohmic loss in the feed structure of arrays.

viii. Extraneous radiation from feed and junctions.

ix. Excitation of surface waves.

Size of microstrip antenna comes in both advantages and disadvantages but there are some applications where the size of microstrip antenna is outsized for any use. The size of a microstrip antenna is inversely proportional to its frequency. At frequencies lower than microwave, microstrip patches don't make sense because of the sizes required.

The narrow bandwidth is one of the main drawbacks of these types of antennas. A straight forward method of improving the bandwidth is increasing the substrate thickness [15]. However, surface wave power increases and radiation power decreases with the increasing substrate thickness, which leads to poor radiation efficiency. Therefore various other techniques are presented to provide wide-impedance bandwidths of microstrip antennas. Some of the techniques in principle are suitable feeding techniques and impedance matching networks, insertion of slot, slit and notches on the microstrip antennas. Feeding technique has a large number of adjustable parameters like length, width and shape. Other ways to overcome these limitations are decreasing dielectric constant of the substrate, increasing thickness of the substrate and width of the patch.

Another problem to be solved is the low gain for conventional microstrip antenna element. Cavity backing and lens covering [16] are the two ways to improve the gain. Cavity backing has been used to eliminate the bidirectional radiation and thereby providing higher gain compared with conventional microstrip antenna. The integrated lens microstrip antenna can be treated as composite antenna combined by microstrip radiator elements and dielectric lens, which is very useful for high frequencies applications. Antenna array [17] is another effective means for improving the gain of the microstrip antennas.

Applications of Microstrip Antennas

Numerous commercial requirements are fulfilled by the use of microstrip or printed patch antennas. Out of many shapes, rectangular shaped patch antennas are the most widely used antennas. Microstrip patch antenna fulfils most requirements for mobile and satellite communication system [18] and many kinds of microstrip antennas is designed for this purpose. Aircraft, spacecraft, satellite, and missile are others dominant applications, where the use of microstrip antenna is most suitable due to its size,weight, cost, performance, ease of installation, and low-profile nature. Also there are other government and commercial applications in the area of mobile radio and wireless communications where the requirement of this antenna is suitable.

Some notable applications for which microstrip antennas are developed and found suitable are:

i. Satellite Communication Direct Broadcast Service.

ii. Mobile Communication Systems.

iii. Doppler and other Radars.

iv. Missile and Telemetry.

v. Remote Sensing and Environmental Instrumentation.

vi. Satellite Navigation Receivers.

vii. Radio Altimeter.

viii. Biomedical Radiators and Intruder Alarms.

ix. Personal Wireless Communication Systems and Service.

A large number of commercial needs are met by the use of these antennas [19]. The various application include the ubiquitous Global Positioning System (GPS), ZigBee, Bluetooth, WiMax, Wireless Fidelity (WiFi) and wireless communication systems. Navigational applications, such as asset tracking of vehicles as well as marine uses, have created a large demand for antennas. It finds extensive use in radio frequency identification (RFID) and radar system [20] in the area of manufacturing, transportation and medical. In short, microstrip antennas fulfil the demands of a flexible, less weight antenna system. In recent years printed monopole microstrip antenna finds use in Satellite Digital Audio Radio Services which is an alternative to audio commercial broadcasts in automobiles. The advantages of using antennas in communication systems will continue to generate new applications which require their use. They are the device which enables all the wireless systems that have become so ubiquitous in our society. The material costs for wired infrastructure also encourages the use of antennas in many modern communication systems. With the increase in the awareness of the possibilities of Microstrip antenna [21], particularly due to its radiation mechanism and functional performance, the number of applications will continue to grow. Wide bandwidth is required for certain applications in communications, electronic support and counter measures, radar and radiometry [22].

1.3.2 Microstrip Antenna Structure

The most basic form, of a Microstrip patch antenna consists of a radiating patch [23] on one side of a dielectric substrate; it has a ground plane on the other side as shown in Figure 1.2.

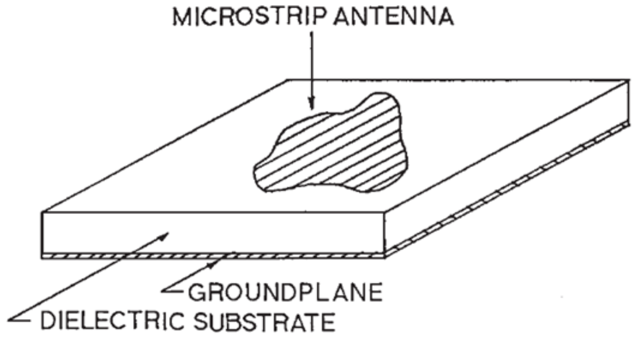

Figure 1.2: Geometry of a Microstrip Antenna

In its simplest form a microstrip antenna is a dielectric substrate panel sandwiched [24] in between two conductors. The lower conductor is called ground plane and upper conductor is known as patch. Commonly used frequencies for microstrip antenna is in between 1 GHz to 100 GHz. The patch is selected to be very thin. Patches are normally made of material such as gold or copper and design in to any shapes. These conducting metals are the main choice because of their low resistivity, resistance to oxidation, and ease in soldering and adhere well to substrate. The feed line and radiating patch is etched on the dielectric substrate.

The radiating patch can be design in various shapes according to the desired characteristics but circular, square and rectangular shapes are common due to ease of fabrication and analysis. Their radiation characteristics are similar, despite the difference in the geometrical shape, because they behave like a dipole. If the thickness of the dielectric substrate is large the surface waves and spurious feed radiation increases, this will reduce the bandwidth of the antenna The feed radiation also leads to undesired cross polarized radiation. Microstrip patch antennas radiate chiefly due to the fringing fields between the edges of the patch and the ground plane. A thick dielectric substrate with low dielectric constant is desirable for a better performance. This will delivers better efficiency and radiation. But this property has a tendency towards increasing the size of the antenna. For the design of a compact shape, substrate dielectric constants should be high. However such design will be less efficient and has narrower bandwidth.

Impedance matching is required between antenna and feed line to ensure the maximum transfer of energy from source to radiating elements. An approximately selected port location will provide matching between antenna and feed line.

Through decades of research it was identified that the performance and operation [25] of a microstrip antenna is driven mainly by the geometry of the printed patch and the material characteristics on to which the antenna is printed. The patch geometries are generally rectangular but square, circular and triangular patches are also possible. Depending upon the characteristics of the transmitted electromagnetic energy, the radiating element may be square, rectangular, triangular elliptical or circular in shape and must be separated by a finite distance from the ground plane. A sheet of dielectric substrate is introduced between these two conducting layers.

Most commonly used microstrip antenna is the rectangular and circular patches. These patches can be used for the simplest and the most demanding applications. For example, characteristics such as dual-frequency operations,circular and dual polarizations, broad bandwidth, beam scanning and so on are easily obtained in these patches. Any new numerical or analytical technique is standardized by first applying to these geometries. Undoubtedly the simplest microstrip antenna configuration is rectangular microstrip patch antenna. Hence this investigation deals with broadband rectangular microstrip antenna.

1.3.3 Feeding Techniques for Microstrip Antenna

The feed guides the electromagnetic energy from the source to the region under the patch. Some of this energy crosses the boundary of the patch and radiated into space.

The signal in a microstrip patch antennas is fed by a variety of methods.

The methods of feeding are categorized into two categories namely contacting and non-contacting. In the contacting method, the input radio frequency power is fed directly to the patch by a connecting element such as a microstrip line. In the non-contacting scheme, often regarded as indirect one, electromagnetic field coupling is done to transfer the power between them microstrip line and the radiating patch. The four most popular feed techniques are the microstrip line feed, coaxial feed,aperture coupling feed, proximity coupled microstrip feed, and coplanar waveguide feed. Different feeding methods influence different antenna properties such as bandwidth,radiation pattern, polarization, gain and impedance. In practice, the coaxial and microstrip feed is the most commonly used feeding method. Matching is usually required between the antenna and the feed lines because input impedance differ from customary 50 ohm line impedance. An appropriately selected port location will provide matching between the antenna and its feed line. A brief description of each of these feeding methods is given in the section below.

Microstrip Line Feed

In this type of feed technique, as shown in Figure 1.3, a conducting strip is connected directly [26] to the edge of the Microstrip patch. The conducting strip is smaller in width as compared to the size of the patch. This method is the easiest to fabricate as this feeding arrangement and radiating patch can be printed on same dielectric substrate. This arrangement provides a planar structure.Due to this advantage a large arrays may be designed using edge-fed patches.The drawback is the radiation from the feed line, which leads to an increase in the cross-polar level. Also, in the mm wave region of spectrum, the dimension of the feed line is equivalent to the dimension of the patch size, leading to increased undesired radiation. The feed arrangement to the patch may also have an inset cut in the patch. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. This is an easy feeding scheme, because it provides ease of fabrication and simplicity in modelling as well as impedance matching.

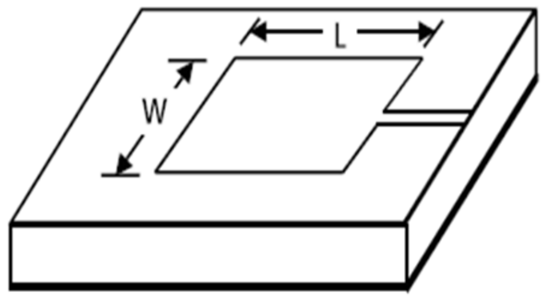

Figure 1.3: Microstrip Antenna fed by Microstrip Line Feed

Coaxial Probe Feed

The coaxial feed or probe feed [27] is the most common techniques used to feed printed patch antennas. It is shown in Figure 1.4. This feed can be given at any desired location within the patch to achieve impedance matching. 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 coaxial feed or probe feed method gives low radiation loss. The main advantage of this feed is that it can be placed at any desired location inside the patch to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it gives less bandwidth and is not so easy to use since a hole has to be introduced into the dielectric substrate. Also the hole has to be drilled in the substrate and that the connector protrudes outside the bottom ground plane. It is not completely planar and this feeding arrangement makes the configuration asymmetrical. For thicker dielectric substrates, the increased coaxial feed or probe feed length gives the input impedance more inductive, resulting impedance matching problems.

For thick substrates, which are generally employed to achieve broad band both the above methods of direct feeding the microstrip antenna have problems. In the case of a coaxial feed, increased probe length makes the input impedance more inductive, leading to the matching problem. For the microstrip feed,an increase in the substrate thickness increases its width, which in turn increases the undesired feed radiation. In large thickness dielectric substrate the microstrip line feed and the coaxial feed suffer from problem with probe reactance and surface wave excitation. The indirect feed, as discussed below solves these problems.

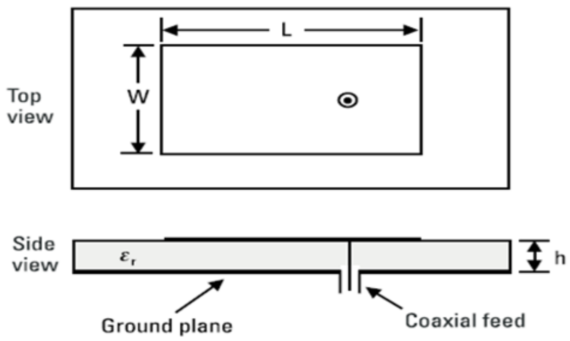

Figure 1.4: Microstrip Antenna fed by Coaxial Probe Feed

Aperture Coupled Microstrip Feed

In an aperture coupling [28] the field is coupled from the feed line to the resonating patch through slot in the ground structure, which is placed in between the two substrate. On bottom substrate feed line is there and on top substrate radiating patch. In the aperture-coupled microstrip antenna configuration, the field is coupled from the microstrip line feed to the radiating patch through an electrically small aperture or slot cut in the ground plane, as shown in Figure 1.5. The coupling aperture is generally centered under the patch. This help in lowering the cross-polarization because of configuration symmetry. The amount of coupling from the feed line to the patch is decided by the shape, size and location of the aperture. The slot aperture can be either resonant or non-resonant. The resonant slot provides another resonance in addition to the patch resonance thereby increasing the bandwidth, but this lead to an increase in back radiation too. As a result, a non-resonant aperture is normally used. The performance is moderately insensitive to small errors in the alignment of the different layers. Different substrate parameters can be chosen for the two layers for getting an optimum antenna performance. This feeding method gives increased bandwidth. [29].

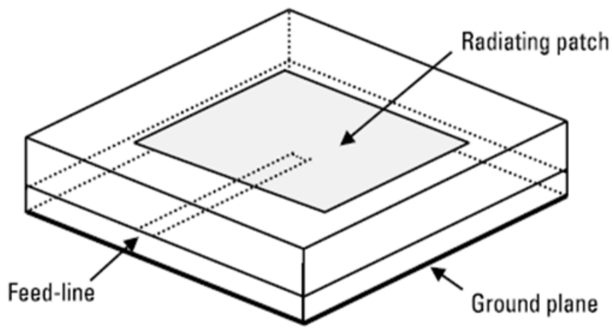

Figure 1.5: Microstrip Antenna fed by Aperture Coupled Microstrip Feed

Proximity Coupled (Electromagnetically) Microstrip Feed Technique

A configuration of this non-contacting microstrip feed used two-layer substrate with the microstrip line on the lower layer and the patch antenna on the upper layer as shown in Figure 1.6. This feeding method [30] contains two dielectric layers i.e. one is a radiating patch layer and on lower layer feed line is fabricated with a ground plane on back side. The two substrates are separated by a common ground plane. The microstrip feed line on the lower substrate is electromagnetically coupled to the patch through a slot aperture in the common ground plane. The slot can be of any shape or size and these parameters can be used to improve the bandwidth. The radiation from the open end of the feed line does not interfere with the radiation pattern of the patch because of the shielding effect of the ground plane. This feature also improves the polarization purity [31]. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The notable feature of this feed configuration is wider bandwidth, which is primarily because of an inclusive increase in the thickness of the microstrip patch antenna. This technique has the provision of choosing separate substrate for the patch and the feed line in order to achieve an optimize performances. The major drawback of this method is difficulty in fabrication due to multiple layers which need proper alignment. Also in this method the thickness of the antenna increases.

Coplanar Wave Guide Feeding (CPW)

The coplanar waveguide feed [32] has also been used to excite the Microstrip antenna. In this method, the coplanar waveguide is printed on the ground surface of the patch as shown in Figure 1.7. The line is excited by a coaxial feed and is terminated by a slot whose length is nearly one quarter of the

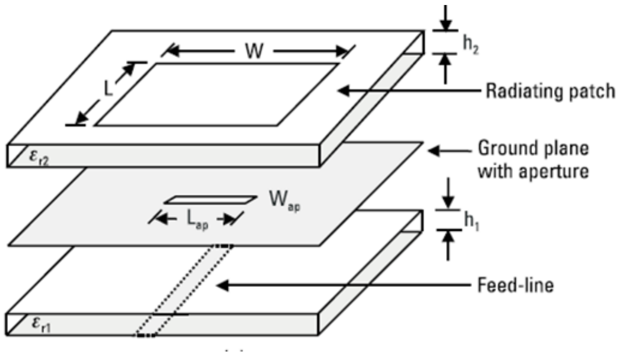

Figure 1.6: Microstrip Antenna fed by Proximity Coupled Microstrip Feed

slot wavelength. This feeding method has been widely used for wireless communications due to its many features such as wide band width, simple structure, a single metallic layer, less numbers of soldering points, and easily compatible with other circuits etc. The main disadvantage of this method is the high radiation from the relatively longer slot. This can be better by reducing the slot dimension and adjusting its shape in the form of a loop.

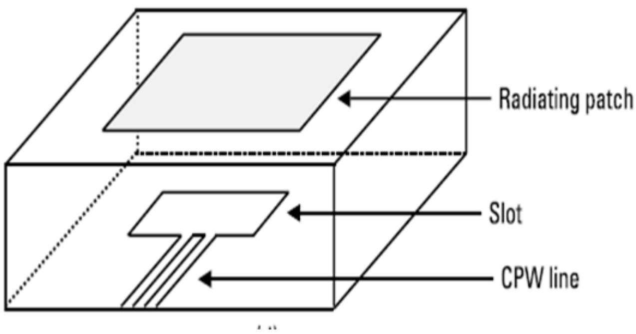

Figure 1.7: Microstrip Antenna fed by Coplanar Wave Guide Feed

A comparison between various types of feeding techniques [33] is made and shown in the Table 1.3.

Characteristic	Microstrip Feed Line	Co-axial Feed	Aperture Coupled Feed Line	Proximity Coupled Feed	CPW feed
Spurious feed radiation	More	More	Less	Minimum	Less
Reliability	Better	Poor	Good	Good	Good
Ease of fabrication	Easy	Difficult	Difficult	Difficult	Difficult
Impedance matching	Easy	Easy	Easy	Easy	Easy
Bandwidth achieved	2-3%	2-3%	3-5%	15%	3%

Table 1.3: Comparison of Different Types of Feeding Techniques

1.4 Analysis of Rectangular Microstrip Antenna

The microstrip antenna has a thin dielectric substrate in between a two-dimensional radiating patch and a ground plane. For analysis purposes [34] it is categorized as a two-dimensional planar component. The analysis method is divided into two groups.

In the first group of method, the analysis is done on the basis of equivalent current distribution around the edges of the radiating patch. In this group the two widely used analytical techniques are the transmission line model and the cavity model. This group present more more physical insight but less accuracy.

In the second group, the analysis is based on the distribution of the electric current distribution in between the radiating patch and the ground plane. This group is analysed by numerical methods based on the Method of Moments (MoM) and the Finite Element Method (FEM). This group requires more rigorous analysis and hence takes longer simulation time, but they give a more accurate result. Besides these to popular methods other methods such as Finite Difference Time Domain (FDTD) Method [35], Finite Integration Technique (FIT), Green Function Methods, etc. are also well used for the analysis [36].

1.4.1 Transmission Line Model

This model is simple in analysis and also presents a good physical insight. It is helpful in understanding the basic performance of the microstrip antenna. In this model [37] the radiating patch element is viewed as a transmission line resonator without any transverse field variations. The variation of the field is taken along the length. The radiating patch is represented by two slots separated by the length of the resonator. Fringing fields at the open circuited ends is the main source for the radiation. Originally this model was proposed for rectangular patches but later on it has been extended for all generalized shape of the patch. It is also most suitable for rectangular microstrip antenna. The drawback of this model is its accuracy. It is less accurate. Although it is easy to use, but in this case all types of configurations can't be analysed as it does not take care of field variation in the orthogonal direction of propagation.

In this approach, the microstrip antenna is represented as parallel plate transmission line, with no transverse field variation, and connected by two radiating slot of dimension W and height h. The slots are represented high impedance terminations of the transmission line. When excited, the two open ends which are normal to the direction of propagation radiates only. The resonant characteristic of it depends on the length L of the patch. The direction of the propagation of the electromagnetic wave is along the z-direction. A representation of this structure is shown in the Figure 1.8. Fringing effect accounts for the radiation from the edge of the patch. The

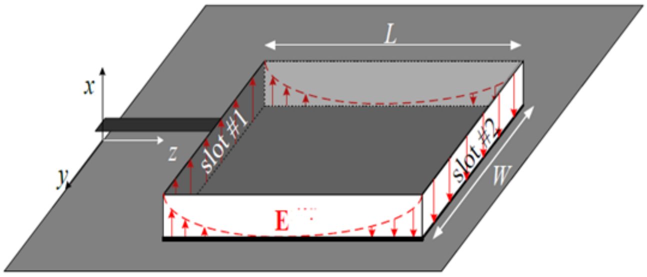

Figure 1.8: Representation of Microstrip Antenna using Transmission Line Model

resonant length is more than the physical length due to this fringing. The resonant length or the effective length of the patch is represented as L_{eff}. The electric field distribution along the patch is shown in the Figure 1.9 along with the two lengths stated.

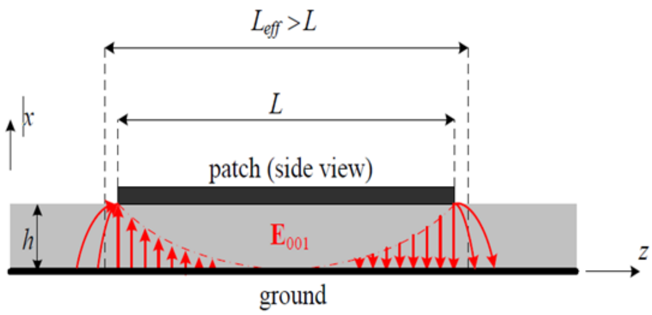

Figure 1.9: Electrical field Distribution in Microstrip Antenna using Transmission Line Model

The dominant mode is TM_{001} and the resonant frequency of the antenna is dependent on the effective length of the patch. The equation relating effective length and resonant frequency is given as:

$$L_{eff} = \frac{\lambda_0}{2} = \frac{v}{2f^{001}} = \frac{c}{2\sqrt{\epsilon_{eff}}}\frac{1}{f} \tag{1.19}$$

$$\therefore f = \frac{v}{2f^{001}} = \frac{c}{2L_{eff}\sqrt{\epsilon_{eff}}} \tag{1.20}$$

1.4.2 Cavity Model

This model [38] gives more accurate result as compared to transmission line mode. It also gives good physical insight of the behaviour of the field on the radiating patch. Here the portion in between the radiating patch and the ground plane is treated as a cavity. The cavity is surrounded by magnetic walls around the periphery and from the top and bottom side it is enclosed with the electric walls. The field inside the cavity is uniform since the thickness of the substrate is small. The field underneath the radiating patch is expressed as a sum of the various resonant modes of the two-dimensional resonator. The fringing fields occurred around the periphery. The fringing fields and the radiated power are not enclosed inside the cavity but they are distributed at the edges of the cavity. The radiation loss from the antenna, the conductor loss, loss due the loss tangent of the dielectric substrate and sky wave loss are responsible for the total radiation of the antenna. The radiated power in the far field is computed from the magnetic current around the periphery. An alternate way of computing the radiation effect [39] is the introduction of the impedance boundary condition at the walls of the cavity. The only drawback of this model is its complex analyses.

The Transmission line method is inadequate in its description of the real processes when a patch is excited. It takes into account only the modes where the energy propagates only in the longitudinal z direction. The field distribution along the x and y axes is assumed uniform. Though the dominant is prevalent but the performance is also exaggerated by higher-order modes.

The cavity model is a more common model [40] in analysing the microstrip antenna, which imposes open-end conditions at the side edges of the patch. Here the patchesa are represented as a dielectric-loaded cavity with the electrical walls at the top and bootom of the cavity, and and the magnetic wall is around the periphery of the patch.

A schematic diagram of the patch using this model is shown in the Figure 1.10.

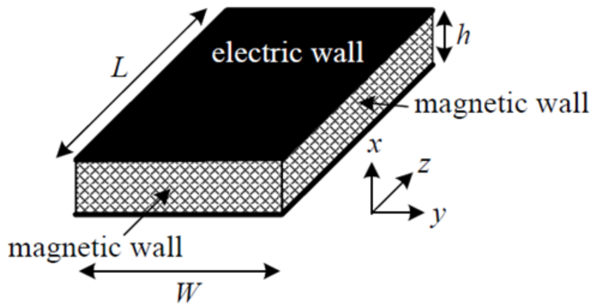

Figure 1.10: Representation of Microstrip Antenna using Cavity Model

In a magnetic wall the H-field is purely normal i.e. n̂ x $\vec{H} = 0$; and E-field is purely tangential i.e. n̂ . $\vec{E} = 0$.

The thickness of the substrate is assumed to be very small in this method of analysis. The waves generated and propagating below the patch experience considerable reflection at the edges of the patch. Merely a small fraction is being radiated. This model assumes that the E field is purely tangential to the slots formed between the ground plane and the edges of the patch. Moreover, it considers only modes with no H field component.

Assuming the material of the substrate is truncated and limited to the periphery of the patch, the four side walls represent four narrow slots, and the radiation takes from these slots. Here the field inside the cavity is assumed to be zero, and the influence of the field in the outside infinite region is represented by the surface currents. These currents are on the surface of the cavity. The filed is concentrated under the patch region as the height of the substrate is very small. The current density of the patch is maximum at its edges. The equivalent magnetic current density for the dominant TM_{001} is shown in the Figure 1.11. It reveals that the magnetic current densities are co-directed and are of equal magnitudes at slot no 1 and 2. They are also of constant values along x-direction and y-direction. There are electrical walls at x = 0 and x = h. so at these two points the

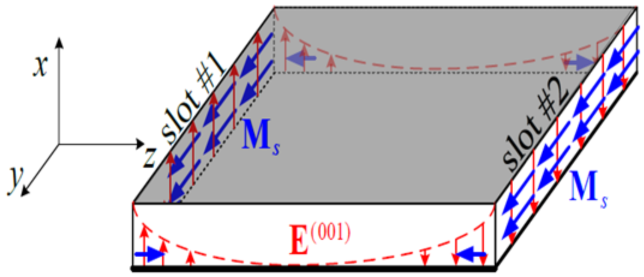

Figure 1.11: Magnetic Field Distribution in Microstrip Antenna using Cavity Model

tangential Electric field components are zero. Hence, the E - fields are given as:

$$E_x = \frac{1}{j\omega\mu\epsilon}(\frac{\partial^2 A_x}{\partial x^2} + k^2 A_x); E_y = \frac{1}{j\omega\mu\epsilon}(\frac{\partial^2 A_x}{\partial x \partial y}); E_z = \frac{1}{j\omega\mu\epsilon}(\frac{\partial^2 A_z}{\partial x \partial z}) \quad (1.21)$$

The magnetic field in the x and y direction vanishes at z = 0 and z = L. similarly at y = 0 and y = W, the x and z components of the magnetic field vanishes. Therefore the H-fields are given as:

$$H_x = 0; H_y = \frac{1}{\mu}\left(\frac{\partial A_x}{\partial z}\right); H_z = \frac{1}{\mu}\left(\frac{\partial A_x}{\partial y}\right) \quad (1.22)$$

The frequencies are calculated by using Eigen value equation, and is given as:

$$\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{W}\right)^2 + \left(\frac{p\pi}{L}\right)^2 = \left(\omega_r^{(mnp)}\right)^2 \mu\epsilon \quad (1.23)$$

Hence,

$$f_r^{(mnp)} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{W}\right)^2 + \left(\frac{p\pi}{L}\right)^2} \quad (1.24)$$

The dominant mode is the mode with the lowest resonant frequency. Since, the length of the patch is lower than the width of the patch i.e. $L < W$. Hence, the lowest resonant frequency mode is TM_{001}. This is the exactly the same mode as resulted in the transmission line model. The resonant frequency corresponding to this is given as:

$$f = \frac{1}{2\pi\sqrt{\mu\epsilon}}\frac{\pi}{L} = \frac{c}{2L\sqrt{\mu\epsilon}} \tag{1.25}$$

1.4.3 Method of Moments

In the method [41], the surface currents are used to model the microstrip patch. Here polarization currents in the dielectric slab are used to model the fields in the substrate. An integral equation is formulated by taking the effect of unknown currents on the radiating patch microstrip patches and the feed lines along with their images on the ground plane. The integral equations are converted into algebraic equations. This method considers the fringing fields outside the physical boundary of the radiating patch. Hence it provides a more exact solution. IE3D and ADS software uses this method for the computational analysis.

1.4.4 Finite Element Method

This method [42] is more suitable for volumetric configurations. Here the plane or volumetric structure region is divided into a number of finite surfaces or volume elements. These discretized units or finite elements are of well-defined geometrical shapes. It computes the integration of certain basic functions over the entire radiating patch.The solution of the wave equations with inhomogeneous boundary conditions are tackled by dividing it into two boundary value problems. One involves inhomogeneous boundary condition with Laplace's equation and second one is homogeneous boundary condition with an inhomogeneous wave equation. HFSS software uses this method for their computational analysis.

1.5 Design Tools

High Frequency Structural Simulator (HFSS) and Advanced Design Software (ADS) are electromagnetic software design tools for the design and simulation of the antenna. Beside these two, other design software tools are IE3D, CST and FEKO. All these electromagnetic software tools are based on different computational techniques.

1.5.1 High Frequency Structural Simulator (HFSS)

, It is a three dimensional software, is based on Finite Element Method (FEM) and is more accurate for designing a three dimensional antennas. In this case the results are more close to the experimental results since the analysis is done with more insight into the volumetric structure. It is one of the tools used for the design and analysis of antenna, complex high frequency RF electronic circuit elements and transmission lines. FEM Element can perform electromagnetic simulation of three dimensional structure of any arbitrarily-shaped. Its aim is to provide a three dimensional electromagnetic simulation to designers working on radio frequency circuits, MMICs and signal integrity applications. Each HFSS solver incorporates a powerful and automated solution process to the specified geometry, material properties and the desired output. It generates an efficient and accurate mesh for solving the problem using the selected method. It was originally developed by Professor Zoltan Cendes and his students at Carnegie Mellon University. Prof. Cendes and his brother Nicholos Cendes founded Ansoft and sold this software to HP and bundled into Ansoft product under a marketing relationship. After 10 years of partnership they separated away and later on Ansoft was later acquired by Ansys.

1.5.2 Advanced Design Software (ADS)

It is one of the commercial available electronic design automation software produced by Keysight technologies. Its analysis is based on Method of

Moments technique and is more useful in the analysis of the planer antenna. It is also globally leading electronic design automation software for radio frequency application, microwave and high speed digital applications. It supports every step of the design process right from the schematic capture, layout, design rule checking. It produces the frequency-domain and time-domain circuit simulation along with the electromagnetic field simulation. It is useful in allowing the engineer to fully characterize, optimize and design a radio frequency based application. The electromagnetic simulation is done by partial differential equation solution of the Maxwell's equations based on the method of moments. It also combines full-wave and quasi-static electromagnetic solution to provide insight into the behaviour of antenna design, Microwave Integrated Circuit, Radio Frequency Board and Signal Integrity. ADS was was originally developed by a Belgian company named Alphabit. The company was acquired by Hewlett-Packard and it later became a part of Agilent Technologies.

1.6 Ultra Wide Band (UWB)

Ultra Wide Band is defined as a system having a large bandwidth in excess of 500 MHz. This high band ranges from 3.1 GHz to 10.6 GHz in the Super High Frequency (SHF) range of frequency. The signals in the UWB are pulse shaped wave compressed in time rather than sinusoidal wave compressed in frequency. The bandwidth of the Ultra Wide Band signal is very large as compared to narrowband signal, and this prime property of it provides the Ultra Wide Band signal to operate over wider frequencies. It transmits data at very high data rates by transmitting pulses of energy. The Ultra Wide Band frequency spectrum is achieved by these very short duration pulses. Normally, the duration of pulses is on the order of a few nanoseconds.

The FCC, in February 2002 amended the Part 15 [43] rules which govern unlicensed radio devices to include the operation of UWB devices. The FCC also allocated a bandwidth of 7.5 GHz, ranging from 3.1 GHz to 10.6 GHz to UWB applications. It is the largest spectrum allocation for unlicensed use ever granted. The frequency allocation and the bandwidth for the UWB system and the other existing narrowband wireless system is shown in the Figure 1.12 [46].

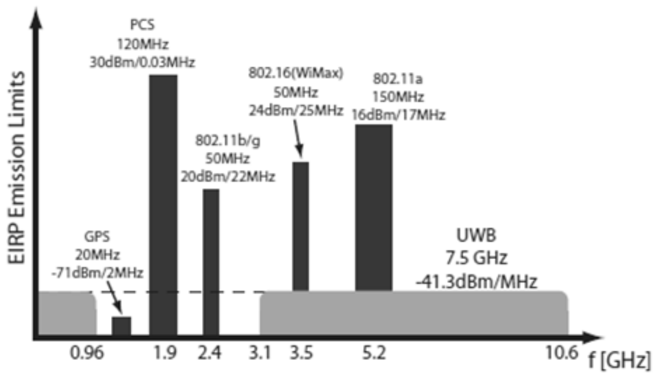

Figure 1.12: Frequency Allocation of Ultra Wide Band System and Existing Wireless Systems

The FCC ruling states that any signal that occupies at least a bandwidth of 500 MHz in the spectrum can be used in UWB systems. This rule is applicable to any technology that satisfy this minimum spectrum of 500 MHz and also compatible with all other requirements for UWB.

1.6.1 Origin of UWB

The main advantage of this system lies in the famous Shannon-Hartley theorem. According to this theorem the channel capacity is proportional to bandwidth for a given signal to noise ratio.

The equation of Shannon-Hartley is:

$$C = Blog_2(1 + SNR) \tag{1.26}$$

Where, C stands for the channel capacity or the maximum data rate, B denotes the channel bandwidth. SNR is the signal to noise ratio in a band limited channel. The equation also state that the channel capacity in a given bandwidth can be increased by increasing the transmitted signal power. The power can't be increased significantly as all portable devices are powered with batteries. Therefore a large frequency bandwidth is the only solution of achieving the high data rate. The trade-off between power and bandwidth spark the motivation for the development of wideband communication systems that includes as spread spectrum and Ultra Wide Band. The trade-off between power and bandwidth exists in analog communication also. Frequency modulation (FM) signal uses more bandwidth than amplitude modulation (AM) signal, but they provide a higher signal quality. Therefore, any wireless communication system operating over short distance, having low propagation loss and less variation, high data rate can be achieved by employing wide bandwidth occupancy.

The essence of the Shannon theorem is that the transmit data rate can be increased significantly by employing a huge channel. Now, Ultra Wide Band is a system having an Ultra Wide frequency bandwidth, so a huge data rate or channel capacity can be achieved by this system. Also Ultra Wide Band systems are operating at extremely low power transmission levels; hence it also provides a secure and highly reliable communication solution. Its low energy density makes unintended detection quite difficult. The antenna for the UWB system should be small in size, low in cost and easily fabricated on a high frequency circuit board [44]. The radiation pattern of the UWB antenna must be omni-directional. This means that the transmitted waves radiated from the antenna should be travel in all directions. The numerical value of the Voltage Standing Wave Ratio (VSWR) of the antenna in the operating range of UWB frequency should be less than 2 with the return loss of less than -10 dB. The gain of the antenna should be relatively constant over UWB frequencies with a numerical value of less than 5 dB. Also there would be no distortion to the waves as it is radiated from the antenna.

UWB technology [45] is considered as one of the most promising wireless technologies of promising a revolution in high data rate transmission with low power. This would enable the personal area networking industry for new innovations and greater quality of services.

Ultra Wide Band provides significant advantages in many of growing wireless communications, areas. It has a number of encouraging advantages that present a better solution to the existing broadband wireless than any other technologies. The prime advantages of Ultra Wide Band frequencies are very higher bandwidth, huge transmit data rate, low power consumption and less multipath fading. It can deliver a capacity of several Giga bits per second with a short distance.

1.6.2 Applications of UWB

Short-range high-speed communication [46] appears to be the most popular application of UWB. While short-range communications is the killer application of UWB, it is worth mentioning that UWB is also capable of long-range communications. This should come as no surprise since the UWB technology originated in short-pulse radar systems. In terms of commercial usage this is widely applicable in high speed Local Area Network / Wide Area Network [47] with more than 20 Mbps of data rate, in Avoidance radar, for altimeter in aviation sector, tags for intelligent transport systems, in the use of intrusion detection, for the purpose of geo-location.

Although much of the hype about ultra wideband has been associated with commercial applications, the technology is equally suited to military applications. One of the advantages is that with the pulses being spread over a wide spectrum they can be difficult to detect. This makes them ideal for covert communications. Short pulse Radar grows with the UWB system, other application includes intrusion detection, precision geo-location and high speed data links. These advantages enable a wide range of applications in radar, imaging and positioning [48]. There are a wide number of applications that UWB technology can be used for. They range from data and voice communications through to radar and tagging. With the growing number of way in which wireless technology can be used, the list is likely to grow.

In a nutshell, Ultra Wide Band can provide a new technology for short-range ultra-high speed wireless communications. It supports a huge data rate in the order of Gbps. This will be a boon in the wireless local and personal area network. Its low power consumption allows it to work with the existing wireless technologies.

There are still challenges to surmount for this technology to perform up to its full potential. It poses several challenges. It's extremely large bandwidth poses a major concern with the possible interference between wide-band narrowband systems. There are well defined regulations of spectrum usage to avoid interference, but the spectrum users have to pay a lot for it and make to convinced that UWB will not cause any undue interference to their existing services. The design of Ultra Wide Band antennas is more challenging than designing conventional antennas. Conventional wideband antennas may transmit UWB signals, but not without distortion. The characteristic parameters of the conventional narrow band also find no match with the requirement of the Ultra Wide Band antenna.

1.7 Satellite Communication

A Satellite Communication (popularly abbreviated as Satcom) is an artificial satellite positioned in space for the purposes of telecommunications [49] it is functioning using radio at microwave frequencies. the communications satellites are mostly stationed in geosynchronous orbits or near geostationary orbits, though low earth orbits are also in use recently.

A satellite link [50] provided the transmission of a signal from an Earth station to a satellite. This is termed as uplink. The satellite transponder receives, down the frequency, and retransmits the amplified signal back to Earth. This is termed as downlink. In the down earth station, the signal is received and re-amplified by Earth stations and terminals. Satellite receivers on the ground include Direct-To-Home (DTH) television set, mobile reception, telephone network, internet links, equipment in aircraft, satellite telephones, and hand-held devices.

1.7.1 Applications of Satcom

In most system applications, one satellite serves many earth stations. With the assistance of earth stations, fixed or transportable, satellites are opening a new era for global satellite multi access channel's data transmission and broadcast of major news events from anywhere in the world. Commercial and operational needs dictate the design and complexity of satellites.
The most common satellite attributes [51] include the following:

i. Improved coverage areas, better quality services and frequency reusability.

ii. Compatibility of satellite system with other systems.

iii. Expandability of the existing system to enhance future operations.

iv. High gain multiple hopping beam antenna systems to enthral smaller aperture earth stations.

v. Increased capacity requirements to fascinate several communication between users.

vi. Competitive pricing as compared to fiber optics and terrestrial networks.

Communications by satellite delivers a number of features that are not readily available with other modes of communication, such as terrestrial microwave, cable, or optical fibre. Noticeable *advantages* of satellite communications are:

i. Distance Independent Costs. The cost comprises in a satellite transmission remains the same irrespective of the distance between the ground stations. Satellite based transmission expenses are more steady tend to be more stable, particularly for international communications over very large distances.

ii. Fixed Broadcast Costs. Broadcasting is the transmission from one transmit ground station to a number of receiving ground stations. The cost involved in the satellite broadcasting of the transmission of messages is not dependent on the number of ground stations receiving the transmission.

iii. High Capacity. Satellite communications links involve high carrier frequencies and consequently large information bandwidths. Normally hundred Mbps of transmission is provided by communications satellites to cater essential services for hundreds of video channels beside with thousands of voice or data links.

iv. Low Error Rates. Satellite links using digital radio allows statistical detection and error correction techniques. Error rates of one bit error in a million bits or better can be regularly succeeded efficiently and constantly.

v. Diverse User Networks. High coverage of the earth by the typical communications satellite allows the satellite to link together many earth stations simultaneously. Satellites are predominantly valuable for accessing remote areas or communities not otherwise accessible by terrestrial means. Satellite terminals can be fixed or movable, and they are operational from the surface or sea or air.

1.7.2 Main Components of Satcom

The main use of a Satcom [52] is to reroute the signals. It picks up signals from a ground station and retransmit it to another ground station, which is located a considerable away from the first. Another use of Satcom is the television broadcasting. Number of programs are first up-linked and then down-linked over wide region. The users having appropriate devices can receive and watch the programs. One of the modern uses of satellite is getting information along with image (commonly known as space/satellite image) of any desired location on earth.

Satellite communications are comprised of two basic elements. One is the satellite component or space component compromising of the satellite & telemetry controls along with the the transponder. The transponder received the uplink signals from the ground station. It also includes a broad band receiver, an input multiplexer and a frequency converter. The prime function of the transponder is the reroute the uplink signals through a high powered amplifier for downlink. The frequency for the uplink and the downlink are different. The frequency conversion occurs in the transponder.

The second component is the ground station or the earth segment. It comprises a base band processor, an up-converter, a high powered amplifier and a parabolic dish antenna for the transmission of the terrestrial data to the satellite. For downlink, the reverse action is being carried and the signals are recollected through dish antenna.

A satellite in orbit has to operate continuously over its complete operational life span. It needs power for the functioning of its onboard electronic systems and communications payload. Sunlight is the main source of power, which is harnessed by the satellite's solar panels. A satellite also has batteries onboard to provide power during eclipse. These back up batteries also recharged by the Sunlight.

1.7.3 Operation of Satcom

Satellites are operating in three different orbits. These are low earth orbit (LEO), medium Earth orbit (MEO) and geostationary / geosynchronous orbit (GEO). LEO satellites are stationed at a height in between 160 km and 1,600 km (100 and 1,000 miles) above Earth. MEO satellites are positioned in between 10,000 to 20,000 km (6,300 to 12,500 miles) from Earth. Satellites do not operate between these two orbits because of the inhospitable environment for electronic components in that area caused by the Van Allen radiation belt. GEO satellites are positioned exactly at 35,786 km (22,236 miles) above Earth's equator. This is a unique orbit in which it completes one revolution around the earth in 24 hours. So the position of the satellite with respect to Earth remains fixed over one spot. Satellite communications use the super high-frequency range for its operation. The working range are C-band, higher X-band, Ku-band for earth to satellite link and Ka-band for inter satellite link. The launching of a satellite into space requires a very powerful multi-stage rocket and correct manoeuvre to propel it into the right orbit. Satellite launch sites use launch vehicle for the placement of satellite in the desired orbit. These sites are Satish Dhawan Space Centre at Sriharikota, India, Kennedy Space Center at Cape Canaveral, Florida, the Baikonur Cosmodrome in Kazakhstan, Kourou in French Guiana, Vandenberg Air Force Base in California, Xichang in China, and Tanegashima Island in Japan.

In a relatively short span of time, satellite technology has developed into a sophisticated and powerful technology. Almost all the long distance communication is dependent solely on the satellites. With increasing video, voice, and data traffic requiring larger amounts of bandwidth, there is huge demand of emerging applications to meet the demand for the satellite services in future.

Short range satellite communication systems are the predominant application areas of Ultra Wide Band technology.

1.8 Motivation

The quest of achieving high data rate spurs the researcher to invent new technology for the ever demanding and ubiquitous wireless communication system. The conception of Claude Ernest Shannon deluges the approach of high data rate by increasing the channel bandwidth. The Ultra Wide Band technology has witnessed substantial progresses in recent years. This technology promises to revolutionize high data rate transmission with low power. Thus it would be offshoot the wireless communication industry with greater quality of services. One of the challenges for the full utilization of its potential is the demand of an appropriate compact antenna.

1.9 Objectives

The objective of the research is as follows:

i. Designing of a compact microstrip antenna in the Ultra Wide Band by using Antenna Design Electromagnetic Software Simulation Tools.

ii. Develop the antenna hardware with the specific requirement.

iii. Testing of the salient parameter of the antenna by vector network analyzer.

iv. Validation of the result by comparing the results achieved from simulation and measurement.

1.10 Chapter Summary

The chapter is concise summary of the antenna in general and microstrip antenna in particular. Along with the description of various active and passive parameters of the antenna, their types and a time line till the development of Ultra Wide Band technology is cited. The parameters of the antenna are discussed in a crisp manner. The chapter briefly describes the microstrip antenna advantages and disadvantages, the various techniques used in the feeding from the source. An introductory note on the progression, motivation and application of the Ultra Wide Band technology is also mentioned. In the end of it brief idea of the satellite communication and its main components are discussed along with its immense utility. In the end the motivation and the objective of the work is presented.

Chapter 2

Literature Review

Research papers on many ultra- wide band antennas have been studied. This is obligatory to set the requirement of the specific work. Some of them are conferred in the literature. The cited reviews are based on the bandwidth expansions, choice of substrate and feeding technique are the important requirements. Numerous techniques have been conveyed by the researchers to acquire the bandwidth enhancement of the microstrip antenna for the Ultra Wide Band characteristics.

2.1 Brief Review Note of the selected Literature

Brief concrete note of the important literature in the Ultra Wide Band is cited below:

Deng et al. [53] proposed Ultra Wideband antenna suitable for W-LAN and WiMAX application. The monopole antenna is fed with a co-planar waveguide. The dual band notched characteristic antenna is also suitable for C-band satellite communications. The desired band notch feature is obtained by a pentagonal slot and double inverted L-shaped stubs on the patch. The antenna is rectangular with dimension of 40 mm by 41 mm and used FR4 substrate of thickness 0.5 mm. The antenna showed a band rejection from 3.2 to 4.25 GHz and 5.1 to 6.15 GHz in UWB region. The antenna is compact and suitable for suppressing the interference in UWB communications.

Zhou et al. [54] proposed and investigated a frequency band-notched monopole UWB antenna. Both the single band and dual band notch antenna is designed and presented. The antenna structure is half disc combined with inverted isosceles trapezoid structure. The band notch feature is achieved by one quarter length of open-ended thin slit on the patch. Multiple slits are used to realize multiple frequency band notched characteristics. The band notch eliminates the interference from 5.15 to 5.35 GHz and also 5.72 to 5.82 GHz. The antenna replaced the addition of costly and bulky filters to avoid the existing WLAN in the UWB communication. The antenna achieved a gain of nearly 5 dB and 2.4 dB at the two designated notched frequency bands with a VSWR of around 3.

Samal et al. [55] proposed a full UWB band antenna from 3.6 to 10.3 GHz. The antenna is coaxially fed microstrip with full ground plane of size 87 mm by 76 mm. It is also unidirectional in nature and important in the application of Wireless Body Area Networks (WBAN). The radiation efficiency of the antenna is close to 60% and the maximum gain is 6 dB with two resonances at 5 GHz and 7 GHz. The slot on the patch of size 48 mm by 26 mm is circular in nature and it is associated with a circular slot, double step notch and T-shaped slit. The existing broad-banding and good directivity is done by this design to enable the UWB behaviour keeping the full ground plane intact. It achieved a two band ranging from 4.3 to 5.5 GHz and 6.7 to 10.1 GHz of range.

Sadat et al. [56] proposed a microstrip antenna with square-ring slot for UWB application. The ring shaped patch dimension of 35 mm by 21 mm is carved on RO substrate of dimension 120 mm by 100 mm. The microstrip feed line is tuning fork shaped stub. The UWB bandwidth is achieved by splitting the designed ring slot antenna and optimizing the fed line by using double split trapezoid shape line. The slot radiators are connected vertically and showed a good resonance in two broad band at 3 to 6 GHz and 7 to 11 GHz of frequency. The antenna has a broadside gain ranging uniformly from 0.2 dB to 4.1 dB, and showed a good linear polarization pattern with good radiation. The reduction in width makes it a compact structure and the antenna provide a VSWR of less than 2.2 over a return loss of less than -8.5 dB was achieved by using slot radiators. These radiators resonates at certain frequency and are connected vertically together.

Sadat et al. [57] proposed a UWB microstrip double patch antenna. The proposed antenna has double patch on the RO substrate of dimension 120 mm by 100 mm. One patch is a rectangular ring and another is H shaped inside the ring. The size of patch is 35 mm by 21 mm. the H-shaped radiating patch acts as a parasitic element. The antenna is fedby a fork shaped tuning stub of a single microstrip line. The introduction of the H-shaped patch offers the full range UWB bandwidth. The antenna also exhibits a band rejection from 5.5 to 7 GHz. The antenna is useful in avoiding the interference in the High Performance Radio LAN system. VSWR of lower than 2 is obtained in the entire UWB region with a return loss of less than -10 dB.

Zivkovic et al. [58] presented a box shaped antenna structure. The same geometrical shaped antennas of different dimension were useful for both narrow band as well as wide band application. The structure of the antenna is symmetrical and uniform. The monopole antenna has a dimension of 120 mm by 120 mm by 30 mm for narrow bending. The broad bending is achieved on smaller dimension of 20 mm by 5 mm by 10 mm on a square substrate of size 80 mm by 80 mm. The radiating element is made from copper and the substrate is epoxy. The fed is done by coaxial probe.

The narrow band antenna had a 3.7% bandwidth at 800 MHz of frequency, whereas in the UWB range it showed a 54% bandwidth in the region ranging from 2.6 to 4.5 GHZ.

Zhang et al. [59] introduced circular shaped microstrip antenna in the UWB range of frequency. Here two kinds of antenna with band notch are presented. Two kinds of band-notched ultra wide-band slot antennas are proposed. The circular radiating patch of radius 15 mm is printed on a square shaped FR4 substrate of edge 40 mm. Fed with a 3 mm microstrip line the antenna had a semi-circular strip. The antenna covered 2.6 to 10 GHz with a VSWR of 2. It has also a band notch ranging from 4.96 to 6.24 GHz. The key feature was the change in the notch frequency by varying the length of the strip on the patch.

Hu et al. [60] presented a band notch characteristic dipole antenna for UWB application. The antenna had a double trapezoidal radiating patch. A T-shaped slot was inserted on the complex structured semi trapezoidal radiating patch. The antenna is fed with microstrip line. The substrate with the permittivity of 2.78 has a dimension of 48 mm by 46 mm by 0.8 mm. It also used a partial ground of size 2.2 mm by 16 mm. The antenna showed a VSWR of less than 2 from 3.1 to 10.6 GHz. It had a band notch from 5.15 to 5.82 GHz of frequency for avoiding the possible interference in Wireless local area network. A good gain of 4 dB is achieved in between 3 to 5 GHz and 7 to 10 GHz of frequency. The radiation pattern of the antenna is omnidirectional in the entire range.

Azim et al. [61] proposed a compact antenna consisting of an annular ring patch. The circular ring patch is fed with microstrip line. The substrate has a dimension of 26 mm by 24 mm by 1.6 mm and permittivity of 4.6. The band notch feature is achieved by inserting a partial annular bend pipe shaped slot on one the lower left side of the patch near the feed line. The band notch is centered around 5.5 GHz of frequency. By varying the thickness of the slot and the position of the patch on the substrate the band notch at Wireless local area network and dedicated short-range communication is proposed. The antenna also uses partial ground plane. The changing position and width of the annular slot affect the center frequency and the bandwidth. The return loss has sharp resonance at 3.5 GHz and 7 GHz of nearly -35 dB. The gain of the antenna is near to 2 dB.

Lech et al. [62] presented a unique finite ground flexible antenna for the UWB application. The antenna is made of two circular coplanar strips carved on a thin and flexible substrate. The substrate has a huge size of 7 cm by 7 cm with a very low thickness of 0.25 mm and permittivity of 3.44. There are two circular shaped patches on the substrate. The inner one is solid of radius 13.5 mm and the outer patch is a circular ring of outer radius 23 mm. The antenna is fed with coplanar co-axial probe. Both the patches are connected to the source by similar rectangular strip. The paper investigates the influence of antenna curvature and the proximity between the radiating patch on the return loss and radiation pattern. It showed a return loss of less than -13 dB from 3 to 15 GHz of frequency. This is achieved by keeping the metallic distance more than 20 mm.

Esfahlani et al. [63] in the research letter proposed a compact single-layer microstrip antenna. The patch of the antenna is annular ring shaped with inner and outer radii of 7.4 mm and 17 mm. The Rogers duroid square substrate has an edge of 40 mm and the thickness is 1.58 mm. The microstrip line single-feed antenna exhibits a sharp dual-frequency with a high frequency ratio. The radiation pattern of the antenna is broadside and symmetrical, and is suitable for space-borne application. The dual frequency is achieved by shorting pin and the sharp resonance is occurred in the region 1.7 to 1.706 GHz and 8.01 to 8.27 GHz. The L-band and X-band resonance is of prime importance in the communication payloads of remote sensing satellites. The dimension antenna is reduced by 46% as comparable to conventional rectangular patch.

Ghassemi et al. [64] proposed a multilayer multi resonator ultra- wide bandwidth antenna. The proposed microstrip antenna is fed with aperture coupled microstrip antenna. The unique microstrip fed line is a tuning fork shaped. The antenna is sandwich within three dielectric layers. It has two slot in parallel to the fed line of length 4 mm and 5 mm, and a slot of length 9.7 mm is vertically crossed on the two. The rectangular patch above the slots substrate has the dimension of 7 mm by 16 mm with an air gap of thickness 2 mm. The substrate used is Rogers duroid with the permittivity of 2.2. A bandwidth of 4.1 GHZ is achieved with one slot. The resonant frequencies and the bandwidth are varied by changing the length of slots and the distance of separation. A VSWR of less than 2 is achieved from 9.8 to 14 GHz. With two slots it achieved a VSWR of less than 2 from 9.8 to 22 GHz. The antenna has a simulated gain of more than 5 dB in the region ranging from 9.8 to 19 GHz and 8 dB gain from 12 to 17 GHz also.

Chatterjee et al. [65] presented an antenna having two sharp resonance frequencies in the UWB region. The antenna is bevel shaped having the dimension of 16 mm by 20 mm. A single layer bevel of size 2 mm by 2.75 mm is cut at top left and another at the bottom right of it. It is fed with coaxial probe of radius 0.8 mm. There is an air gap between the epoxy substrate and copper ground plane. Sharp resonance at 4.25 GHz with a return loss of -32 dB and at 7 GHz with return loss of -28 dB is obtained. Both the resonance peak is narrow bend in nature. This antenna found suitable in short band radio of C-Band and radar application.

Islam et al. [66] proposed an inverted patch structure microstrip antenna useful in the wireless communication in L-band. The proposed antenna has air substrate of height 12.5 mm between the Rogers duroid substrate and ground plane. The patch is made from Aluminium with the dimension of 79 mm by 53 mm. The antenna is fed with coaxial probe. It comprised of 5 slits on one side having same length but different widths of 5 mm, 10 mm and 15 mm. The effect of multi slotted patch and integration of air with substrate give high gain, stable radiation pattern and broadening effect. A bandwidth of 27.62% is achieved with the return loss of less than -10 dB. The antenna has uniform gain of more than 6 dB and the maximum gain obtained is 9.41 dB. The antenna shows the excitation below -10 dB from in lower L band ranging from 1.8 to 2.4 GHz.

Kasi et al. [67] proposed a simple and compact microstrip antenna in the region of Ultra Wideband frequency. The fabricated antenna is consisting of a rectangular patch with two small notch on the top and it is carved on epoxy substrate of size 28 mm by 29 mm by 1.6 mm with a truncated ground plane. It is fed with a thin flared shaped microstrip line of size 3.5 mm by 12 mm. The patch is of dimension 8.5 mm by 11 mm. The simulated antenna achieved the Ultra Wide Band from 3.8 to 12 GHz with a return loss of less than -10 dB. The experimental result showed the achievable bandwidth from 4.5 to 7.9 GHz and from 8.2 to 10 GHz. It has a sharp resonance in the first zone with the maximum return loss of -40 dB at 6.6 GHz. The small antenna shows a good VSWR performance of less than 2 from 3 to 14 GHz. The achieved gain of the antenna is from 1.5 to 4.5 dB.

Lim et al. [68] in his paper proposed a compact rectangular microstrip Ultra Wide Band antenna. The antenna is fabricated with 35 micrometer copper foil over a substrate of dimension 36 mm by 34 mm by 1.6 mm. The patch size is 11 mm by 18 mm and is fed with a double stub shaped microstrip line of length 11.5 mm. The simulated antenna shows operation from 4.1 to 10 GHz. The UWB is achieved by truncating the ground and varying the size of the feed line. The antenna has the maximum gain of 2 dB with a radiation efficiency of more than 80%. The measurement on the fabricated antenna shows a bandwidth of 4.6 to 9.6 GHz.

Chen et al. [69] proposed a small microstrip antenna for Ultra Wideband (UWB) applications. It utilizes the use of reduced ground plane. The substrate use in RO having the permittivity of 3.38 with an overall dimension of 25 mm by 25 mm by 1.52 mm. A notch of size 4 mm and 12 mm is cut in between two strip of size 2 mm by 6 mm on the right side of the patch. One strip is cut from the radiator and the second is attached to the patch. The feed line is microstrip and it is at the center of the patch. The measured result shows a bandwidth of 2.95 to 11.6 with a return loss of less than -10 dB. The ground plane affect the antenna performance is diminished by the notch and strip. The notch and strip also help in the minimizing the overall size of the antenna. The antenna shows a good omni-directional pattern with an efficiency ranging from 79%-95%. The sharp resonance at the lower band makes this antenna useful for mobile devices.

Soliman et al. [70] proposed a circular microstrip antenna for Ultra Wideband (UWB) applications. The antenna is consisting of a circular patch of radius 7.5 mm on one side of RO substrate. The permittivity of the substrate is 3.38 and the dimension is 10 cm by 10 cm by 1.52 mm. A circular slot of radius 15 mm is cut on the back side of the substrate. The feeding is microstrip line with 3.5 mm width. Optimization is done on the radii of the patch and slot along with separation between them to get the desired parameters. The antenna achieved a dipole like radiation with an efficiency of 80%. It also achieved again ranging from 3 to 6 dB over the UWB frequency. Towards the high frequency it shows an increasing gain but reducing efficiency.

Shinde et al. [71] proposed a band notch UWB antenna. The band notch of is centered at 7.5 GHz. The proposed antenna is complex in shape.

The patch is pentagonal in shape of side length of 9.5 mm. It is printed on the epoxy substrate of dimension 32 mm by 22 mm by 1.6 mm. The feeding is through a double step shaped microstrip line of width 2.6 mm. A thin slot is cut near the one edge of the patch. The ground plane is partial and truncated on both side of the microstrip line with gap of 0.5 mm. The performance of the antenna is dependent on this spacing along with partial ground plane dimension. The band notch is achieved by the slot. The antenna provides two bands. One band is from 2.8 to 6.7 GHz and it is useful for the service of WiMAX and WLAN. The second band is from 8.1 to 10.7 GHz and it covers the X-band applications. Both the bands have more than 25% of fractional bandwidth as desired in the need of Ultra Wideband communication system. The gain of the antenna is 0.4 dB.

Adan et al. [72] presented the design of a circular microstrip antenna for UWB communication. The patch of the antenna has the radius of 9 mm, and it is etched over epoxy substrate of size 34 mm by 36 mm. The ground plane is partial of size 11 mm by 36 mm. The feeding line is two step microstrip line. The thinner line is close to the patch and the wider one is near the source. A slot of size 3 mm by 10 mm is cut on the extreme left of the patch. The dimension of the transmission line has a great effect on the impedance bandwidth. The monopole antenna achieved a bandwidth of 8.4 GHz ranging over the entire UWB band. It has one sharp resonance of -40 dB at 10 GHz of frequency. The gain of the antenna is varying from -5 dB to 1.3 dB.

Rahayu et al. [73] proposed various slotted antenna. They presented simulation result with different combination and shape of slot. The various slot shaped used are T-slot, L-slot, ring slot, dual asymmetrical L slot. The result shows the best resonance at 5 GHz of frequency with -40 dB of return loss. The optimization of the dimension of different slots is done to get the desired result. The patch size is 15 mm by 12 mm and printed on epoxy substrate. The width of every slots are kept at 1 mm while the length is varying from 5 mm to 11 mm. The radius of the ring is 3 mm. The antenna is fed from a 3 mm wide microstrip line. The matching bandwidth is obtained by the placement of ring slot near the feed point andthe rectangular slots near the edge. The small size of the antenna would be useful in the WPAN applications. The dual asymmetric L slot gives dual resonance at 5 GHz and 10 GHz. the radiation pattern is symmetrical and omnidirectional.

Tammam et al. [74] in his article proposed a small size monopole antenna. The antenna has band rejection characteristics at WLAN and WiMAX frequency. The semi-circular patch is etched on epoxy substrate of size 12 mm by 18 mm with partial ground plane. The thickness of the patch is 3.5 mm. it is centrally slotted with 1 mm thickness and a notch is kept at the top of it. The optimization on the width of the slot and the size of the ground plane is done to achieve the result.

Norzaniza et al. [75] in his paper proposed a rectangular compact microstrip Ultra Wideband antenna. The antenna has band notch features from 5.1 to 5.8 GHz for WLAN application. It a rectangular antenna of size 18 mm by 11 mm etched on the epoxy substrate of dimension 36 mm by 34 mm by 1.6 mm. The antenna is fed from a double step microstrip line of different width. The band notch is achieved by the introduction of a rectangular U-shaped slot in the middle of it. The size of the slot is 6 mm by 9 mm by 0.8 mm. The operating frequencies of the antenna is ranging from 3.9 to 9.7 GHz.

Wiesback et al. [76] discussed about the various properties and basic design for Ultra Wideband radiation. They presented time domain and frequency domain analysis of the UWB antenna and the principle on the radiation. The focus on the paper is the radiation principle since there are many possible antenna structures. The various antenna mechanism described are aperture coupled Vivaldi travelling wave antenna, frequency independent aperture coupled bow tie antenna, two arm logarithm self-complementary antenna, and multiple resonance monocone antenna with enlarged ground plane. The paper also described partial grounded planer pentagon shaped co-planer waveguide fed antenna and microstrip line fed circular antenna. The advantage sand disadvantages of each classes of the antenna are also discussed. It is concluded with the note that there exist a number of possible Ultra Wide Band antennas, but none of them is suitable for all application. Therefore for a wireless engineer, the choice of the specific antenna depends on the specific need and radiation characteristics.

Azim et al. [77] proposed a tapered shaped slot antenna for UWB application. The rectangular patch is etched on a substrate of size 22 mm by 24 mm by 1.6 mm with the permittivity of 4.6. The antenna used different shape of stub. The optimization is done by taking into account the rectangular, circular, elliptical, square and tapered shape slot on the top of the patch and rectangular tuning stub. Impedance bandwidth is observed with all these and the best result is obtained with the tapered shape. It shows a VSWR of less than 2 within the frequency ranging from 3 to 11.2 GHz. The antenna achieved a maximum gain of 5.4 dB in the higher frequency region. The radiation efficiency of the antenna is stable throughout the UWB region and its value is varied from 60% to 85%.

Elkorany et al. [78] proposed a double slot rectangular patch antenna. The antenna is proposed on epoxy substrate of dimension 100 mm by 100 mm by 4 mm. The rectangular patch size is 30 mm by 40 mm and two square shaped slots are cut on its two side. The edge of the slots is of 7 mm and 17 mm. It is fed with coaxial probe method. The desired UWB frequency is obtained by optimizing the height of the substrate and varying the dimension and position of the slots. The antenna shoes a resonance from 4 to 10 GHz of frequency.

Gautam et al. [79] proposed a co-planer waveguide fed UWB antenna. It uses an inverted L-shaped strip on the monopole antenna. The overall size of the substrate is 25 mm by 26 mm by 1.6 mm. Here two ground plane are etched on the two side of the patch and the coaxial probe is fed in the middle of the patch. The antenna has multiple slots with different length to get the desired result. Many simulation results are presented with the varying dimension of the slots and ground plane. A VSWR of less than 2 is obtained from 2.6 to 13 GHz of frequency. The antenna shows fair uniform omni directional pattern over all frequencies.

Hassanien et al. [80] proposed a rectangular monopole microstrip antenna for UWB application. The simulated antenna uses a square shaped epoxy substrate of size 30 mm by 30 mm by 1.6 mm. The patch dimension is 16 mm by 12.5 mm. It has a partial ground plane of size 30 mm by 8 mm. A U-shaped slot of dimension 8 mm by 1.5 mm is cut to get the desired resonance frequency. The antenna has a maximum gain of 5.5 dB and the achieved the VSWR of less than 2 over the entire UWB frequency. The desired UWB frequency is achieved by the variation in the dimension of the ground plane and the slot.

Wu et al. [81] proposed a single-layer microstrip antenna for Ultra Wide Band applications. The antenna has an array of rectangular microstrip patches. It is arranged in the log-periodic way. The feeding is done by proximity-coupled method. The overall dimension of the antenna is 320 mm by 110 mm. The antenna uses 11 radiating elements and achieved a VSWR of less than 2.5 from 2.26 to 6.85 GHz of frequency. Both the simulated and the measured antenna show a stable directional pattern. It also achieved an overall good gain of 6.5 dB in the frequency ranging from 2.4 to 6.6 GHz.

2.2 Chapter Summary

The need of the hour in today ultra wide band technology is the planer and compact antenna. In the various research papers cited in the literature review it has been found that some of the researchers have attained the desired antenna operating in the ultra wide band frequency. Most of the antenna structures are not compact. Some of the researcher presented a complex structure. The antenna having high gain is bigger in dimension. Some of the researcher created band notch characteristic in the antenna as per the requirements. The researchers have used both the rectangular and circular patch. The sizes of the rectangular patch antennas are in terms of cm. It has been found in these literature surveys that there is gap in the design of the antenna having simple rectangular structure with minimum regular slots. The ultra wide band antennas cited also lacks a double peak resonance. The general technique of the feed is the coaxial and microstrip line. The literature review presented the papers cited in the transaction on antenna and propagation, and progress in electromagnetic research. The review is a collection of the Ultra Wide Band microstrip antenna design work using different ways such as slots, notches and truncated ground plane techniques.

Chapter 3

Antenna Design

The overall goal of a design is to achieve specific performance characteristics at a stipulated operating frequency. The first step in designing the microstrip antenna is to select the operating frequency and an appropriate substrate [82]. The substrate characteristics involved the dielectric constant and loss tangent, their variation with temperature and frequency. In order to give support and protection for the patch element the dielectric substrate must be strong and able to endure high temperature during soldering process and resistant towards chemicals that are used in fabrication process. A schematic diagram of a rectangular patch shaped microstrip antenna fed with microstrip line is shown in the Figure 3.1.

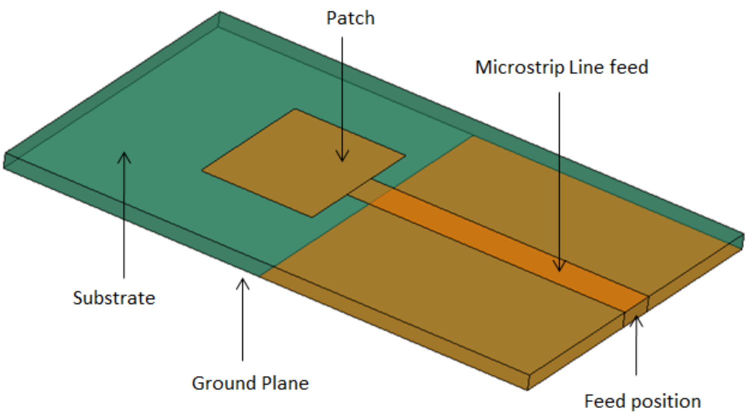

Figure 3.1: Planer Structure of a Rectangular Microstrip Antenna

Substrate thickness and permittivity are the parameters to determine the electrical characteristic of the antenna. Thicker substrate will increase the bandwidth but it will cause the surface waves to propagate and spurious coupling will happen. This problem can be reduced by using a suitably low permittivity substrate. The radiating patch of the microstrip antenna has a very thin patch made of copper or gold. The ground and patch are separated by dielectric substrate bearing low dielectric loss. The important characteristic of microstrip antennas is their inherent ability to radiate efficiently despite of their low profile.

3.1 Design Specifications

The two foremost parameters for the design of a rectangular Microstrip Patch Antenna are:

3.1.1 Frequency of Operation

The resonant frequency of the antenna must be suitably selected. The designed antenna must be able to operate around this frequency range. To design the specific antenna in the Ultra Wide Band region (3.1 GHz to 10.6 GHz), the initial operating frequency is chosen to be around 6.5 GHz, which is around the mid of the Ultra Wide Band region.

3.1.2 Substrate Selection

The next step is to choose a suitable and appropriate substrate. The substrate dielectric constant plays a similar role as that of substrate thickness. A substrate with low value of dielectric constant is helpful in increasing the fringing field at the patch periphery. It also accounts for better radiating power. A high loss tangent reduces the efficiency of the antenna by increasing the dielectric loss. Therefore in most of the design the material with low dielectric constant and very low loss tangent is chosen. But it is shown that the broad band antenna design is achieved easily with the high tangent loss. A high tangent loss reduces the Q-factor of the antenna [83], which in turn increases the bandwidth of it. FR4 epoxy substrate with dielectric constant of 4.4 and loss tangent of 0.02 is most cost effective material, at least in the UWB range as suggested by existing literature. The other available material are Rogers duroid with a permittivity of 2.21, loss tangent of 0.001 and RO having permittivity of 3.0 loss tangent 0.001. Rogers duroid substrate provides a sharp resonance and hence not very much suitable for broad band. Further, the commercial availability of this material is not viable. Same is the case with RO which provides a good response in the narrow band region and have better cost effectiveness than the Rogers Duroid.

The height or the thickness of the rectangular microstrip antenna is associated with the substrate height or thickness. It is denoted by h and usually its value falls in between 1 mm and 2 mm. In the initial determination of the dimensions (length and width of the rectangular microstrip antenna) the height of the substrate is kept at 1.5 mm. the rectangular patch antenna stops resonating with a very thick substrate. The limitation on the height of the substrate [82], for a given material and operating frequency is governed by the equation 3.1 as below:

$$h \leq 0.06 \frac{c}{2\pi f \sqrt{\epsilon_r}} \tag{3.1}$$

Here h, ϵ_r, c and f are height of the substrate, permittivity of the substrate, velocity of electromagnetic wave and operating frequency respectively.

3.2 Dimensions of the Rectangular Microstrip Antenna

Length and width are the two critical parameters for the designing of the rectangular microstrip antenna. The length of the patch plays an important role in the determination of the resonant frequency of it. The width of the patch has less effect on the resonant frequency and radiation pattern. But, on the other hand, it greatly affects the radiation efficiency of the antenna and plays a greater role in the bandwidth of it.

The width W of the radiating patch [84] is given as:

$$W = \frac{c}{2f} \text{ x } \sqrt{\frac{2}{(\epsilon_{r+1})}} \tag{3.2}$$

A plot of width of patch with respect to the frequency ranging from 3 GHz to 11 GHz (Ultra Wide Band range) is plotted for three different substrate as shown in Figure 3.2. These three substrates are FR4 epoxy of permittivity 4.4, Rogers duroid (RT) of permittivity 2.2 and Ceramic (CR) of permittivity 6.1 [36]. It is obvious from the equation and plot that, the width of the patch decreases uniformly with permittivity of the substrate and the frequency of operation.

The height of the substrate has no role in the determination of the width of the patch. The finite thickness, t, of the conducting material adds a correction factor in the width of the patch. The introduction of the thickness of the patch leads to the effective width (W_{eff}) of the patch [36, 82] is given as:

$$W_{eff} = W + \frac{t}{\pi}\left[1 + ln\left(\frac{2h}{t}\right)\right] \tag{3.3}$$

Since the value of the thickness is order of a few micrometer, the effective width is almost same as the width of the patch.

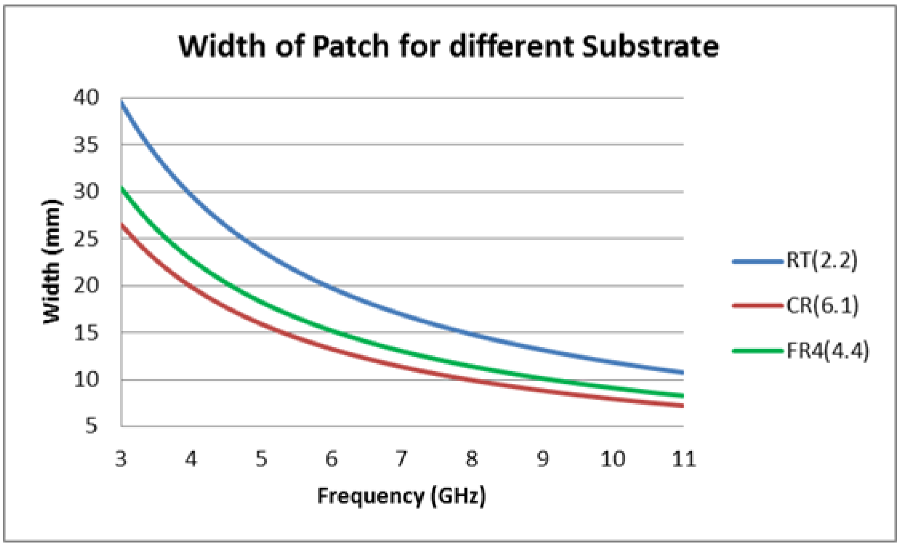

Figure 3.2: Variation of Patch Width with Frequency for Three different Substrate

The length L of the patch [36] is given as:

$$L = L_{eff} - 2\Delta L \tag{3.4}$$

Where, the effective length L_{eff} is given as:

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{eff}}} \tag{3.5}$$

ϵ_{eff} is the effective permittivity of the substrate and is given as:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{[1 + 12\frac{h}{W}]} \tag{3.6}$$

The radiating fields are not confined to the patch, but a small fraction of the radiating fields lie outside the physical dimensions of the patch. This is called the fringing field. This fringing field account for the effective dielectric constant.

Electrically the patch length is bigger than its physical length. Therefore taking into account the normalized extension of the length, the actual length L is given as:

$$L = \frac{c}{2f}\left(\frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{[1 + 12\frac{h}{W}]}\right)^{\frac{-1}{2}} - 2\Delta L \qquad (3.7)$$

The factor ΔL arises due to the effective dielectric constant, which is lower than the actual dielectric constant. This effective dielectric constant is used to account for the fringing effect. The value of this normalized length extension is given as:

$$\Delta L = 0.412h\frac{(\epsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (3.8)$$

The typical value of length extension, ΔL, is in between 0.069 to 0.073 for FR4 epoxy substrate. It is observed from the given equation that for a given frequency, the length of the patch is dependent on the permittivity and height of the substrate. A plot of length of patch with respect to the frequency ranging from 3 GHz to 11 GHz (Ultra Wide Band range) is plotted for three different substrates are shown as Figure 3.3 and 3.4. In Figure 3.3, the height of the substrate is kept constant.

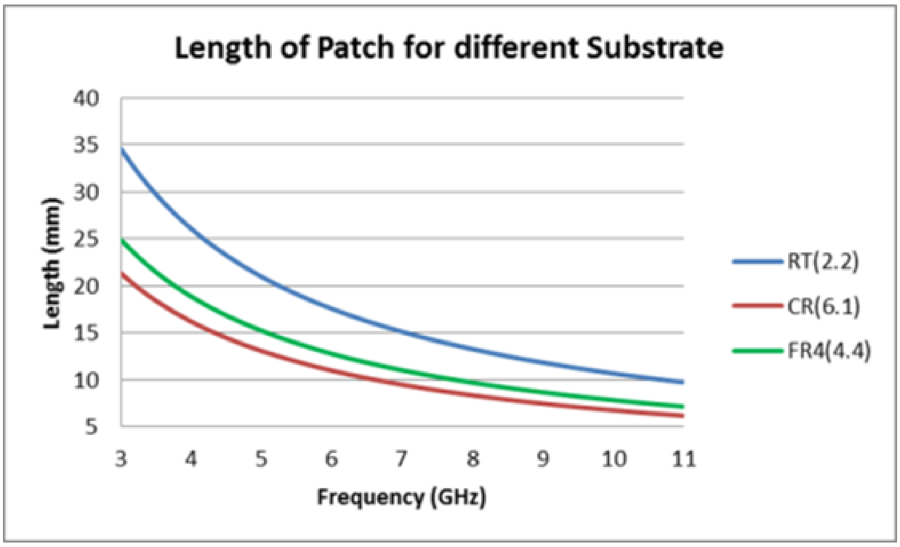

Figure 3.3: Variation of Patch Length with Frequency for Three different Substrate

Figure 3.4 is the variation of the patch length with respect to the frequency for a given substrate having different thickness. The effect of the width of

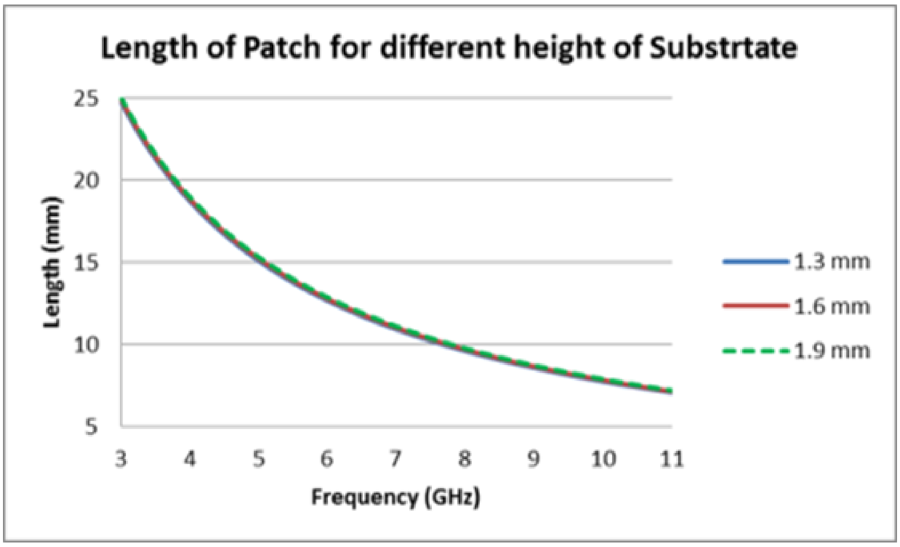

Figure 3.4: Variation of Patch Length with Frequency for FR4 substrate having different height

the patch on the dimension of its length is very minimal. With FR4 epoxy substrate and a central frequency of 6.5 GHz, the length and width of the rectangular microstrip antenna is found to be 11.79 mm and 14.03 mm. As the length of the patch greatly affects the resonant frequency, hence in all further design and discussion the length of the patch is kept at 12 mm. The fractional bandwidth of the rectangular microstrip antenna [85] is given as:

$$\%BW = \frac{A.h}{\lambda\sqrt{\epsilon_r}}\sqrt{\frac{W}{L}} \tag{3.9}$$

Here, A is a constant. Its value depends on the permittivity of the chosen substrate, height of the substrate and the operating resonant frequency.

For the condition that the width of the patch is less than the operating wavelength i.e. if $W < \lambda$, then the different value for the constant A in the above equation is given as:

$$A = 180 \text{ for } \frac{h}{\lambda\sqrt{\epsilon_r}} \leq 0.045 \tag{3.10}$$

$$A = 200 \text{ for } \leq 0.045 \frac{h}{\lambda\sqrt{\epsilon_r}} \leq 0.075 \tag{3.11}$$

$$A = 220 \text{ for } \frac{h}{\lambda\sqrt{\epsilon_r}} > 0.075 \tag{3.12}$$

A plot of the fractional bandwidth with respect to the frequency in the Ultra Wide Band range is shown in Figure 3.5. As the fractional bandwidth is inversely proportional to the permittivity of the substrate, the substrate with low permittivity exhibits high fractional bandwidth. The height of the substrate is taken to be 1.5 mm in the plot shown in Figure 3.5.

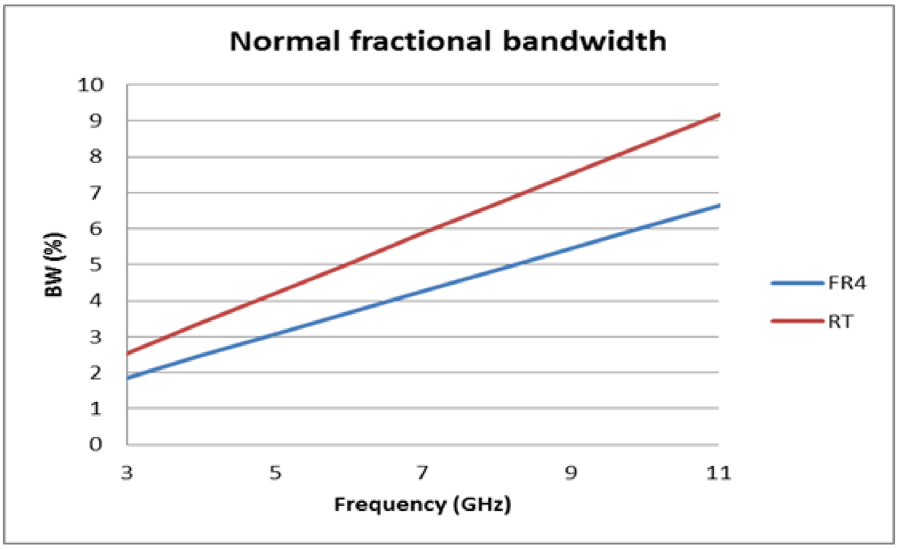

Figure 3.5: Variation of Fractional Bandwidth with Frequency for FR4 epoxy and Rogers Duroid Substrate

It is evident from the Figure 3.5 that the fractional bandwidth of the microstrip antenna is very low. It is also one of the main limitations of the microstrip antenna. Also the fractional bandwidth increases with the frequency. For FR4 epoxy material the fractional bandwidth in the Ultra Wide Band region lies in between 1.85% to 6.65%.

3.3 Procedure to Increase Bandwidth

The main challenge in the designing of the broad band microstrip antenna is to increase the bandwidth. For Ultra Wide Band application the minimum bandwidth requirement is 25%. There are various methods to increase the bandwidth [86, 87]. The ways to increase the bandwidth as employed in this work are listed as:

i. Increasing the Width of the Patch.

ii. Increasing the height of substrate.

iii. Increasing the Dimension of the feed Line.

iv. Length and Position of Slot on the radiating edge.

v. Insertion of Notch on the Corner of Patch.

vi. Suitable size of the Substrate.

vii. Use of Partial Ground Plane (Reducing the Size of the Ground Plane).

Besides these many researcher [30, 88, 89] also utilizes other ways also. These includes:

i. Aperture coupling feeding method.

ii. Use of multi layer substrate.

iii. Shorting pin method.

The simple, compact and cost effective design is always preferred in field of technology. Keeping this in mind, a single layer substrate and microstrip feed line method is chosen. Therefore our aim is to achieve the Ultra Wide Band bandwidth by restricting to the preceding methods.

The input impedance of microstrip antenna mostly depends on its shape, the dimensions of patch, the physical properties of the substrate and the feed type. Therefore, these parameters need to be adjusted to achieve the best geometry for impedance matching. In the present work, various antenna parameters have been optimized to achieve the required Ultra Wide Band specifications. The various parameters for a given resonant frequency and fixed length of the patch are:

i. The width of patch (W)

ii. The height of FR4 epoxy substrate (h)

iii. The length and width of the feed line (L_m and W_m)

iv. The suitable length and width of the slot (L_s and W_s)

v. Position of the slot from the non-radiating edge (p)

vi. Suitable size of the notch at the corners

vii. Size of the substrate (W_G)

viii. Partial ground plane (L_G)

The optimization of first six parameters as listed above is carried out with ADS version 9, while rest two parameters are optimized with HFSS version 12 simulation software tools. A typical diagram showing all these parameter are shown below in Figure 3.6.

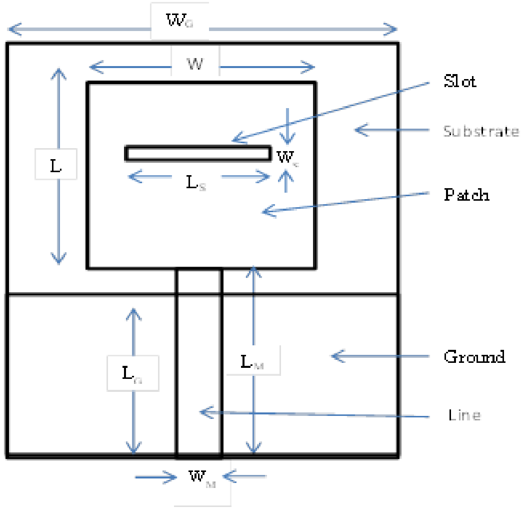

Figure 3.6: Representation of Different Parameters of the Rectangular Microstrip Patch Antenna

3.4 Effect of the Width of the Patch on the Performance of Antenna

For observing the performance of the antenna, return loss and the bandwidth are the two important parameters taken into account for this work. To observe the effect of width of the patch on the return loss and bandwidth, the height of the substrate is kept fixed. This is the height at which the initial length and permittivity of the substrate is chosen. The length of the patch is kept fixed at 12 mm, the permittivity of the epoxy substrate is 4.4. Since the width, obtained by the equation 3.2, is 14 mm. Therefore in this set of observation, the width of the patch is varied from 14 mm to 18 mm. Different simulation results were observed by varying the width. The variation of the return loss with the varying patch width is shown in Figure 3.7. It is important to mention here that the absolute value of return loss is taken for the plot purposes.

Similarly the variation of the bandwidth as a function of width of the patch is shown in Figure 3.8. It is observed from the Figures 3.7 and 3.8 that at

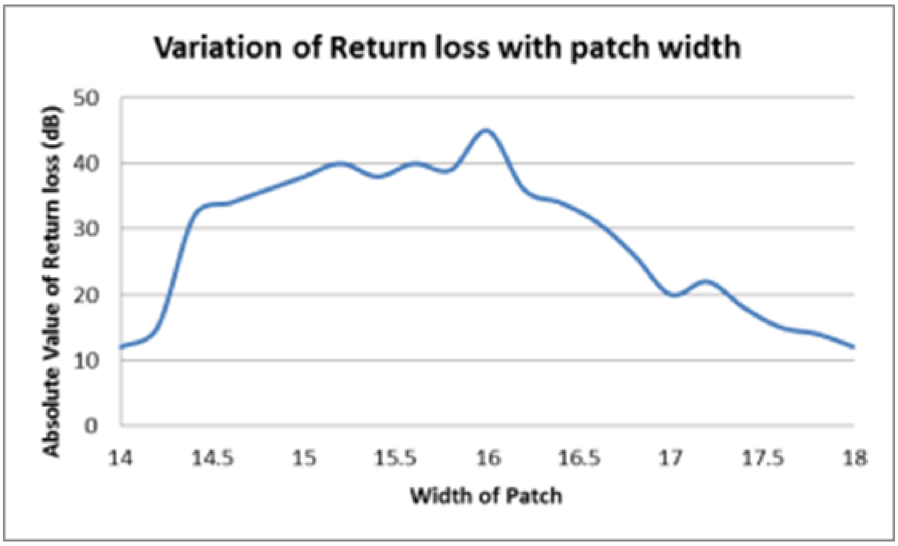

Figure 3.7: Variation of Absolute Value of Return Loss (S_{11}) with of Width of the Patch

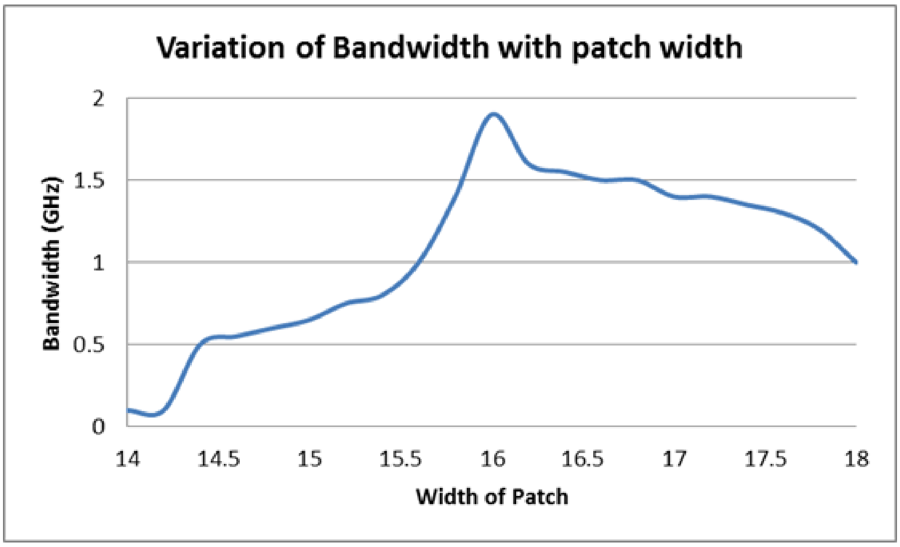

Figure 3.8: Variation of Bandwidth with of Width of the Patch

lower width, near 14 mm, there is very little variation in the return loss and broadening of the antenna. As the width increases from 14.5 mm to 15.5 mm, the bandwidth increased slightly but there is no significant change in the resonant frequency. At a width of around 16 mm there is a significant change in the bandwidth. The antenna is showing a high bandwidth of more than 1.5 GHz and a high return loss near to -45 dB. With a width of more than 16 mm, the bandwidth decreased drastically and the return loss also decreases gradually. The impedance of the patch is a function of its dimension, therefore it is a general observation that with the changing width, the performance characteristics of the patch changes [86]. A larger patch width increases the power radiated and it finally account for increased radiation efficiency. It thus increase the operation bandwidth.

3.5 Effect of the Height of the Substrate on the Performance of Antenna

To observe the effect of height of the substrate on the return loss and bandwidth, the length and width of the antenna are kept fixed at 12 mm and 16 mm respectively. The height of the substrate is varied from 1.0 mm to 2.0 mm. The variation of the return loss is shown in Figure 3.9. The

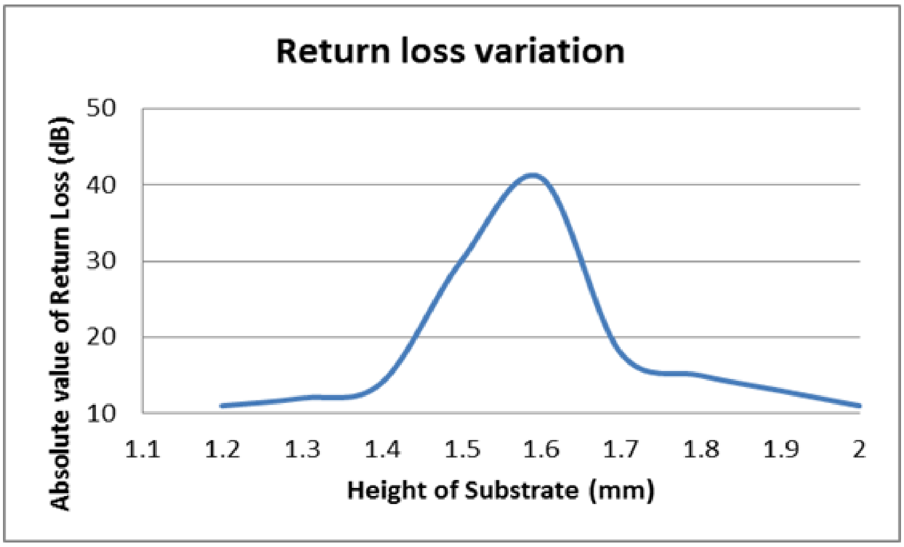

Figure 3.9: Variation of Absolute Value of Return Loss (S_{11}) with of Height of Substrate

bandwidth as a function of the height of the substrate is shown in the Figure 3.10.

Figures 3.9 and 3.10 reveals that, at a height from 1.0 mm to 1.2 mm, the return loss remains below the -10 dB and consequently the bandwidth is

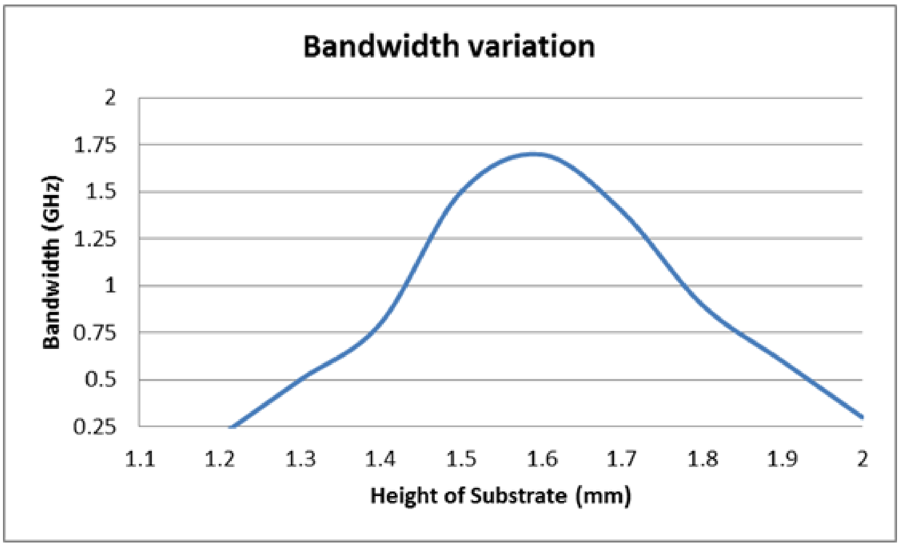

Figure 3.10: Variation of Bandwidth with of Height of Substrate

zero. A significant bandwidth is observed at a height of 1.2 mm. From a height varying from 1.2 mm to 1.4 mm, there is very little variation in the absolute value of the return loss though the bandwidth tends to increase steadily. At increasing height of the substrate beyond 1.4 mm, appreciable return loss and bandwidth are obtained. The best result is obtained at 1.6 mm of height. At this point of observation the bandwidth is near about 1.7 GHz with a return loss of nearly -40 dB. With a height of more than 1.6 mm the performance tends to degrade. Both the return loss and bandwidth goes toward a decreasing value. It is obvious from the Figure 3.10 that both these parameters under observation increases steadily up to 1.6 mm of the height of the substrate, and then started decreasing.

From Figures 3.9 and 3.10, it is concluded that, for a thin substrate particularly below 1 mm, the fringing effect is insignificant. But as the height of the substrate increases it adds more volume to fringing effect, and thereby an increase in the bandwidth and subsequently good radiation is observed. However, as the substrate height increases, surface waves are also generated. These waves extract power from the total available power [90] in the direction of radiation.But beyond a particular height of the substrate for the given dimension of the patch, higher modes are exited and the radiation hampers. This results in the reduction in return loss and the bandwidth.

3.6 Effect of Dimensions of the Microstrip Feed Line on the Performance of Antenna

As the electromagnetic wave travel to different parts of the antenna system they encounter with different impedance at each interface. The electromagnetic waves travel from source to feed line to the antenna, and then radiates to the free spaces. Whenever there is mismatch impedance at any of the interface, it causes some of the electromagnetic waves to reflect back. In the transmission line it forms a standing wave. The standing waves can be reduced by matching the impedance of the antenna to the characteristic impedance of the line. This eventually minimized the energy storage capacity of the transmission line. Hence the dimension of the microstrip feed line plays an important role in the performance of the antenna. A good impedance matching enhances the performance, thereby increase the bandwidth.

To study the effect of dimensions of the microstrip feed line on the return loss and bandwidth, the dimensions of the patch and substrate are kept constant. The length and width of the patch is kept fixed at 12 mm and 16 mm respectively, whereas the height of the substrate is fixed at 1.6 mm. The length and width of the microstrip transmission line is varied and the antenna performance in terms of return loss and bandwidth is simulated.

The minimum width of the microstrip feed line required to excite the patch antenna [91] is given as:

$$W_m = \frac{2h}{\pi}\left[\frac{377\pi}{2Z_0\sqrt{\epsilon_r}} - 0.7 - ln\left(\frac{2 \text{ x } 377\pi}{2Z_0\sqrt{\epsilon_r}} + 1\right)\right]$$

$$+\frac{2h}{\pi}\left[\frac{\epsilon_r - 1}{2.\epsilon_r}\left(ln\left(\frac{377\pi}{2Z_0\sqrt{\epsilon_r}} - 1\right) - \frac{0.6}{\epsilon_r}\right)\right] \quad (3.13)$$

Where Z_0 is the input impedance of the source and is equal to be 50 ohm. ϵ_r and h are the permittivity and the height of the substrate. For the given substrate, the initial minimum width of the microstrip feed line comes out to be 2.06 mm. While the length of the feed line is approximately three times its width [91] and consequently it comes out to be 6.18 mm.

The variation in the absolute value of the return loss as a function of different length of the feed line at different width of the microstrip feed is plotted in Figure 3.11. The length of the feed line is varied form 6 mm to 15 mm. 6 mm of the length is the initial theoretical length and 15 mm is the length at which the bandwidth becomes zero. The plot is with 2 mm, 3 mm, 4 mm and 5 mm of the feed line width. Similarly Figure 3.12 shows

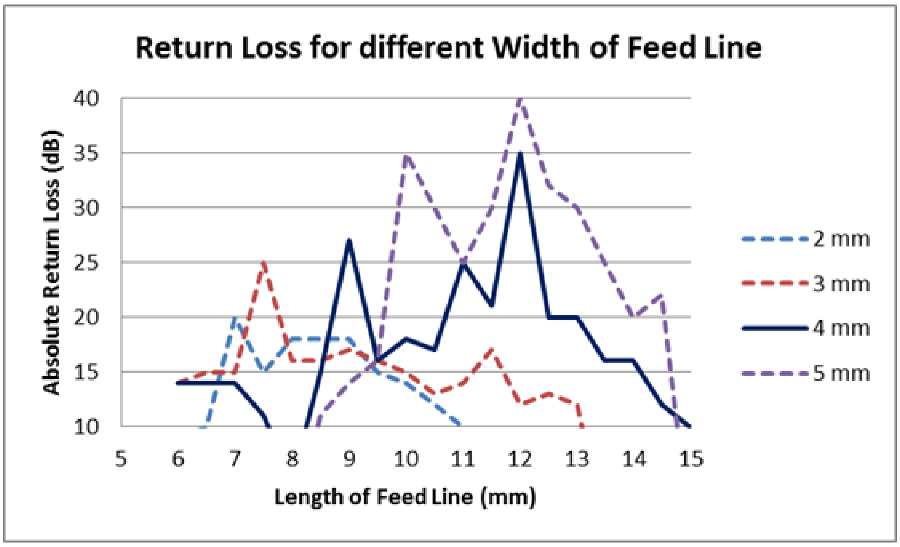

Figure 3.11: Variation of Return Loss (S_{11}) with the Length of the Microstrip Feed Line at Different Width of the Feed Line

the variation of the bandwidth as a function of length of the feed line at different width of the feed line.

Figure 3.12 reveals that with 2 mm width of the feed line, the bandwidth increases steadily and attained a maximum value of nearly 1 GHz at 9 mm of length. The variation of the return loss is very marginal, and is almost constant with the value of -20 dB. With this width, the impedance matching is up to 11 mm of length and after this length the bandwidth becomes zero. With 3 mm of width, the variation of the return loss exhibits a similar pattern as with 2 mm width but the bandwidth is less. The maximum achievable bandwidth is 2 GHz at 12 mm of the length but at this point the return loss is low and it is nearly -15 dB. The observation with 4 mm width shows the best result. In this case, both the variation of the return loss and the bandwidth matches each other. Here the return loss has a zig-zag pattern from 9 mm to 13 mm of the length, but with this length the bandwidth is always higher than 1 GHz.

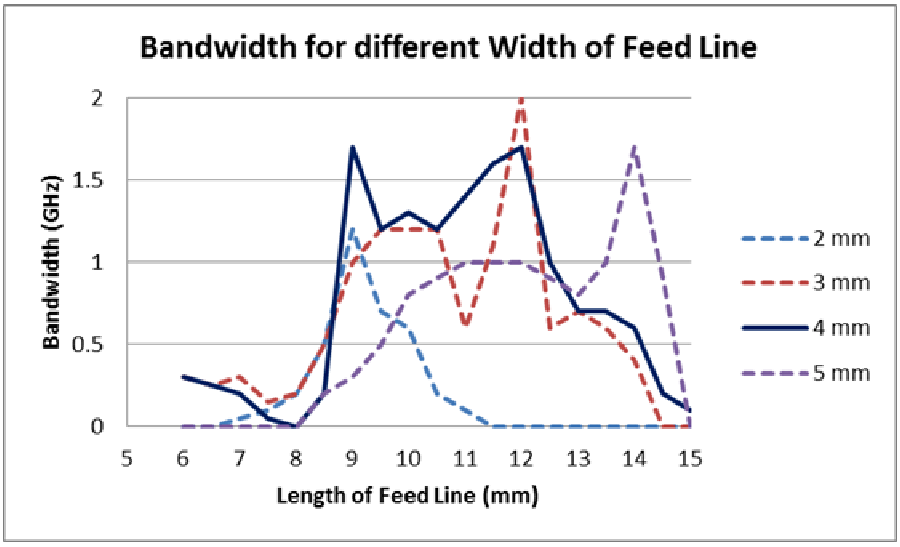

Figure 3.12: Variation of Bandwidth with the Length of the Microstrip Feed Line at Different Width of the Feed Line

The best result is achieved at 12 mm of the length of the feed line. Here the bandwidth is in excess of 1.5 GHz with a high return loss of -35 dB. A high return loss is observed with 5 mm of the width line, but here the bandwidth observed is low. Also there is no matching in between the return loss and bandwidth. In this case, though the return loss of more than -40 dB is achieved at 12 mm of the length of the feed line, but the bandwidth at this length is only 0.5 GHz. Hence, for all further work the width of the feed lien is kept at 4 mm and the length of the line is taken as 12 mm.

The impedance of the microstrip line is mostly depends on its width. With a given width of the feed line, the impedance is almost independent on the variation in the length of it. A feed line is positioned in between the source and the antenna, and the interface occurs between the antenna and the feed line along the width of the feed line. Therefore the impedance varies with the width of it rather than its length. A plot of the impedance of the feed line for different length as a function of width is shown in Figure 3.13.

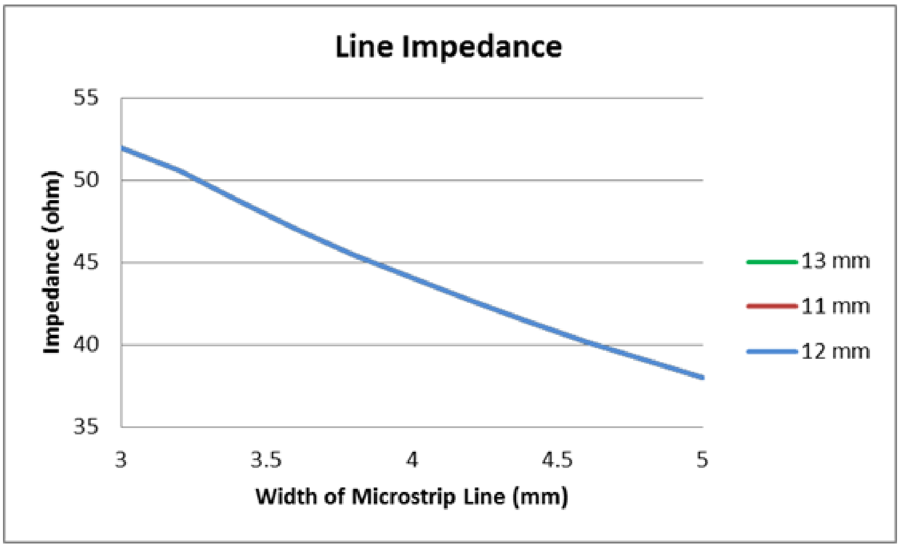

Figure 3.13: Variation of Line Impedance with the Width of the Microstrip Feed Line at Different Length of the Feed Line

The observation is done with three different length of the feed line. It is obvious from the Figure 3.13 that with all these different length the value of the line impedance remains same for a given width of the line.

3.7 Effect of Slot on the Performance of Antenna

A slot is a narrow two dimensional planer structure etched in the metallization on one side of the substrate. Because of its planer geometry, it is well suited in microwave integrated circuits. The effect of the slot is capacitive in nature. It provides a very low cross polarization. Its main advantage is that it enhances the bandwidth of the microstrip antenna [92]. The position of the slot on the patch is important to study because if it is not made at suitable position, an antenna may suffer from undesired mode such as parallel plate mode excitation and its performance tends to degrade [93]. A slot on the patch of the antenna is just like a double edge sword. A typical diagram of a plane rectangular slot loaded microstrip antenna is shown in Figure 3.14. Here, L_s is the length of the slot, W_s is the width of the slot

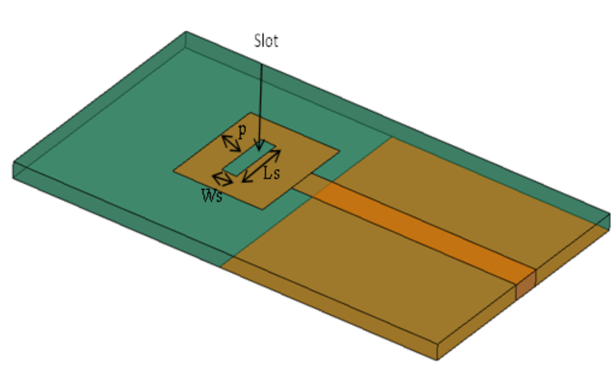

Figure 3.14: Microstrip Antenna Loaded with a Rectangular Slot

and p is the distance or position of the slot form the non-radiating edge of the patch.

The maximum length of the slot, L_S on the radiating patch of the microstrip antenna depends on the width of the patch (W), height of the substrate (h), the dielectric constant of the substrate (ϵ_r) and the resonant wavelength (λ). With FR4 epoxy substrate, having the permittivity of 4.4, and $0.075 \leq \frac{W}{\lambda} \leq 1.0$, the maximum length of the slot, L_S, is given as [94]:

$$L_S = \frac{c}{4f}[1.05 - 0.04\epsilon_r + 0.014(\epsilon_r - 1.42) \text{ x } ln\left(\frac{W}{h} - (2 - 0.3\epsilon_r)\right)$$

$$+(0.1 - 0.04\epsilon_r)\sqrt{\frac{W}{\lambda}} + (0.14 + 0.07\epsilon_r \text{ x } ln(14.7 - \epsilon_r))\left(\frac{h}{\lambda}\right) ln\left(\frac{h}{\lambda}\right)] \quad (3.14)$$

These conditions dictates the maximum length of slot equals to the 11.2 mm.

The length of the patch, width of the patch and length of slot as a function of frequency with FR4 substrate are plotted in Figure 3.15. For a given substrate all these three parameters are showing the same pattern over the entire range of frequency as the parameters are dependent on the substrate property. For a given patch dimensions the length of the slot is always less than the length of the patch. The width of the patch is more than both lengths.

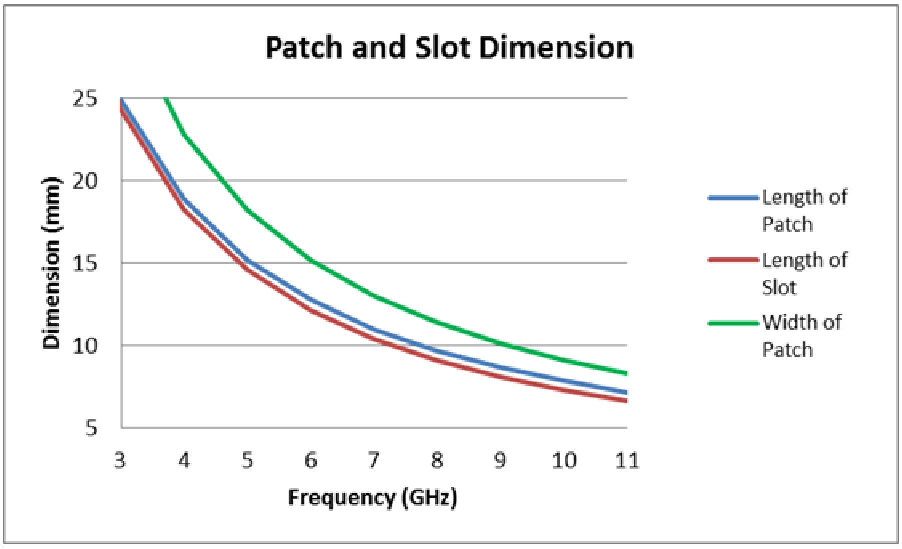

Figure 3.15: Variation of the Dimension of the Patch and the Length of the Slot with Frequency

The effect of the length of the slot, with different position, on the performance of the antenna is simulated on ADS platform. The performance of the antenna is optimized in terms of slot position and length of the slot. The variation of the absolute value of the return loss and bandwidth as a function of the slot position, from the non -radiating edge of the patch, at different slot length are plotted in Figure 3.16 and Figure 3.17 respectively.

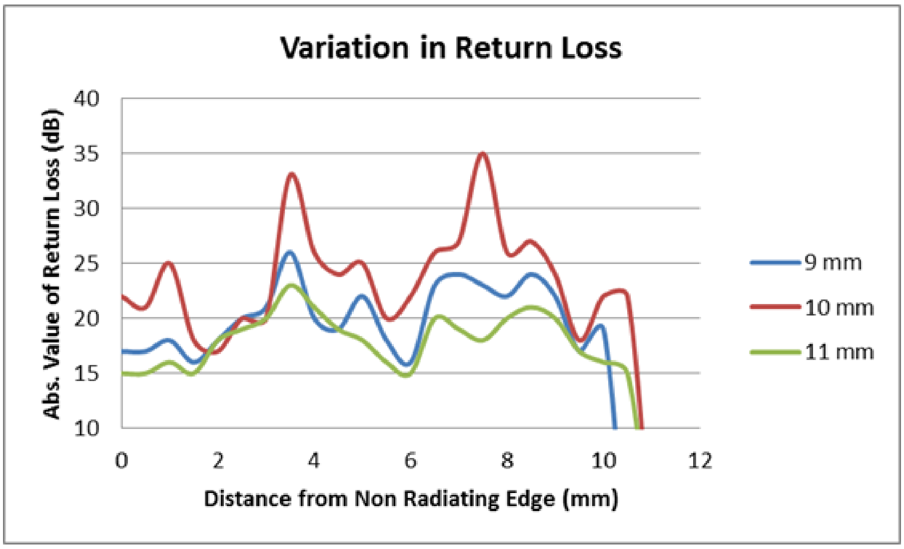

Figure 3.16: Variation of Return Loss (S_{11}) of Different Length of the Slot with the Distance from the Edge

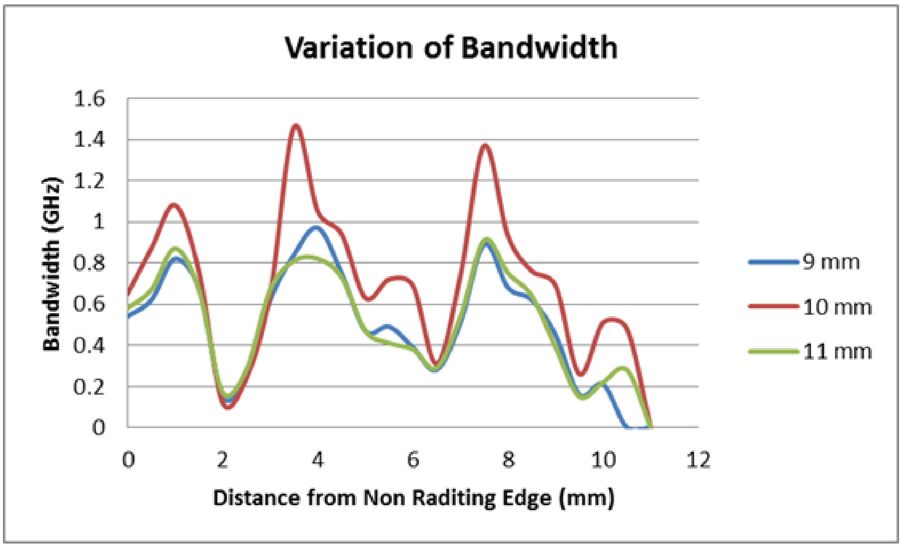

Figure 3.17: Variation of Bandwidth of Different Length of the Slot with the Distance from the Edge

From Figure 3.16 and 3.17, it is clear that both the return loss and bandwidth of the antenna having the same pattern with respect to the position and length of the slot. The best result is obtained with a slot length of 10 mm. It is concluded that a single rectangular slot of length 10 mm placed at 3.75 mm from the non-radiating edge of the patch provide a fairly high bandwidth of 1.4 GHz with a high return loss of -35 dB.

3.8 Effect of Multiple Slots on the Performance of Antenna

To further improve the performance of the antenna, the effect of multiple rectangular slots, particularly with two and three slots, of the same dimension is also simulated. The length of the slot, for this observation, is kept at 10 mm. The performance of the antenna is optimized in terms of the position of the slots. These results are plotted in Figure 3.18 and 3.19.

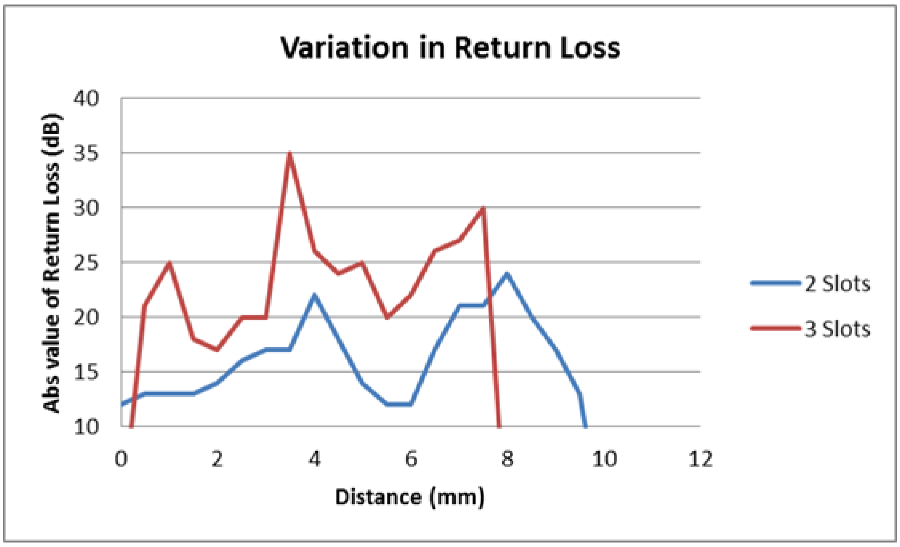

Figure 3.18: Variation of Return Loss (S_{11}) with Number of Slots

Figure 3.16 to 3.19 reveals that the performance of the antenna with single slot and three slots are superior than with two slots. Hence the work is focused for microstrip antenna loaded with single slot and three slots. The effect of three rectangular patches on the bandwidth is more profound. A

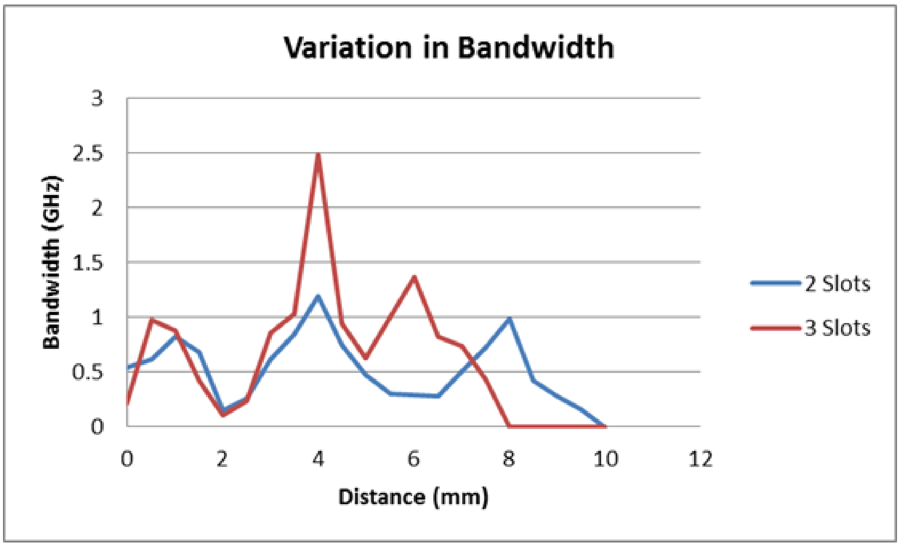

Figure 3.19: Variation of Bandwidth with Number of Slots

bandwidth of 1.6 GHz is obtained with one slot, but a bandwidth of 2.5 GHz is achieved with three slots. The results are compared and presented in Table 3.1.

Configuration	**BW**	**%BW**	**Position of Slot from non-radiating edge**
No Slot	1.6 GHz	18	–
One Slot	1.7 GHz	18	3.75 mm
Two Slots	1.2 GHz	14	3.75 mm, 7.75 mm
Three slots	2.5 GHz	30	1.75 mm, 6 mm, 8.75 mm

Table 3.1: Effect of Slots on Bandwidth of the Antenna

3.9 Effect of Notch on the Performance of Antenna

A notch is very small cut etched at the corner of the radiating patch. The effect of notch has a profound effect on the resonant frequency. A notch reduces the effective dimension of the patch and alter the resonant frequency. Consequently the number of excited modes also altered. The relationship between the resonant frequency and the dimension of patch as well as modes are given by the equations 3.15 and 3.16 [86]:

$$f = \frac{c}{2(L + 2\Delta L)\sqrt{\epsilon_{eff}}} \tag{3.15}$$

Also with respect to the modes and width of the patch, the resonant frequency is given as:

$$f = \frac{c}{2\sqrt{\epsilon_{eff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right] \tag{3.16}$$

The effect of notch on the performance of the antenna is simulated with different dimensions of the multiple notches. With a notch of length 0.5 mm and width 2 mm at the four corners of the patch without slot enhances the fractional bandwidth to as high as 22% while without notch the fractional bandwidth was 18%. The notches at each corner of the patch having three slots, of the same dimension, increased both the absolute bandwidth and fractional bandwidth. The effect of slots and notches is summarized in the Table 3.2.

Table 3.2 reveals three antenna configurations with comparable performance. First antenna has no slot but 4 notches, second antenna has one slot and 4 notches, while thirds antenna has three slots and 4 notches. Therefore these three configurations are considered for further optimization of the performance of the antennas and designated as first test antenna, second test antenna and third test antenna respectively.

Nomenclature	Configuration	BW	%BW
First Test Antenna	No slot but 4 notches	1.7 GHz	22
Second Test Antenna	One slot & 4 notches	1.6 GHz	22
Third Test Antenna	Three slots & 4 notches	3.0 GHz	35

Table 3.2: Effect of Slots and Notches on the Bandwidth of the Antenna

After the optimization of the width of the patch, the height of the substrate, the dimension of the microstrip feed line, the dimension and position of the slot, the number of slots, and the dimension of the notches, the final dimension of the antenna thus obtained is summarized in the Table 3.3.

Parameter	Dimension
Length of Patch	12 mm
Width of patch	16 mm
Height of substrate	1.6 mm
Length of feed line	12 mm
Width of feed line	4 mm
Length of slot	10 mm
Width of slot	0.5 mm
Length of Notch	0.5 mm
Width of notch	2 mm

Table 3.3: Dimension of the Various Parameters of Antenna

Since ADS is a 2.5 dimensional one, therefore the optimization of the length and width of the substrate and the ground plane is not possible. The optimization of these two parameters are done using HFSS software. The final design is achieved by the HFSS software.

3.10 Effect of Finite Dimension of the Substrate on the Performance of Antenna

The length and the width of the substrate also affect the antenna performance. Normally the length and width of the finite substrate is more than the length and width of the patch because the patch along with the microstrip feed line is etched over the substrate. Therefore the overall dimension of the substrate is such that it completely capsulated the patch and the feed line. As a thumb rule the minimum length (L_G) and width (W_G) of the substrate is dependent on the dimension of the patch and height of the substrate [86], and is given as:

$$L_G = L + 6h \tag{3.17}$$

$$W_G = W + 6h \tag{3.18}$$

From the Table 3.2, the total length of patch and the fed line is 24 mm, therefore the length of the substrate is to be kept more than 24 mm. Hence, the initial length and width of the substrate thus obtained from equations (3.17, 3.18) are 21.6 mm and 25.6 mm respectively. The best optimized result is obtained by keeping the length of the substrate as 29 mm and the width of the substrate at 26 mm. The finite ground plane is also of the same size as the substrate. The simulation result is obtained with this dimension of the substrate in HFSS. The simulation is done for all three configurations of the antennas with the above mentioned dimension of the substrate.

The simulated results are presented in the Figures 3.20 to 3.22. The Figure 3.20 indicates that a sharp resonance at 8 GHz with a return loss of -33 dB and bandwidth of 1.5 GHz. The return loss plot with one slot antenna, keeping the all dimension same as the antenna without slot is shown in

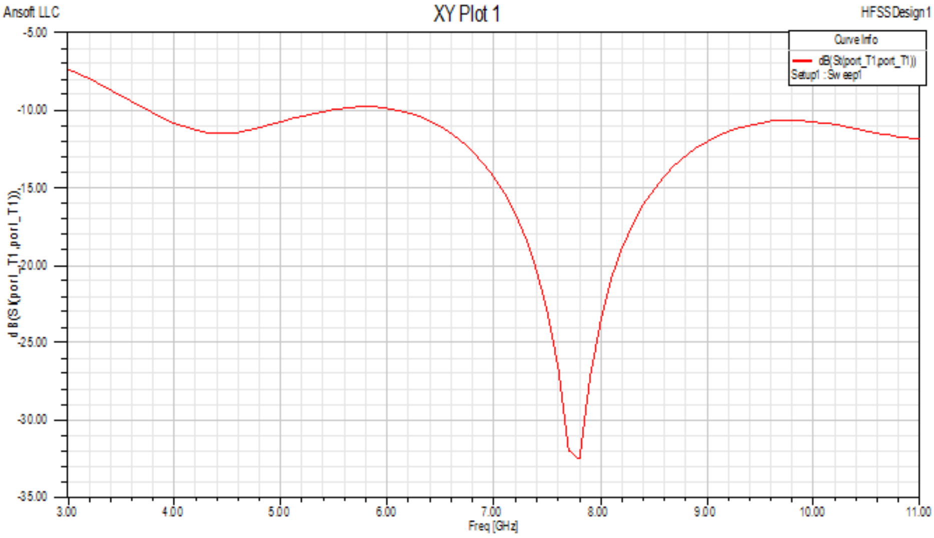

Figure 3.20: Plot of Return Loss (S_{11}) of First Test (Plain) Antenna with Finite Ground Plane

Figure 3.21. In this case the result obtained is near to the earlier one. The

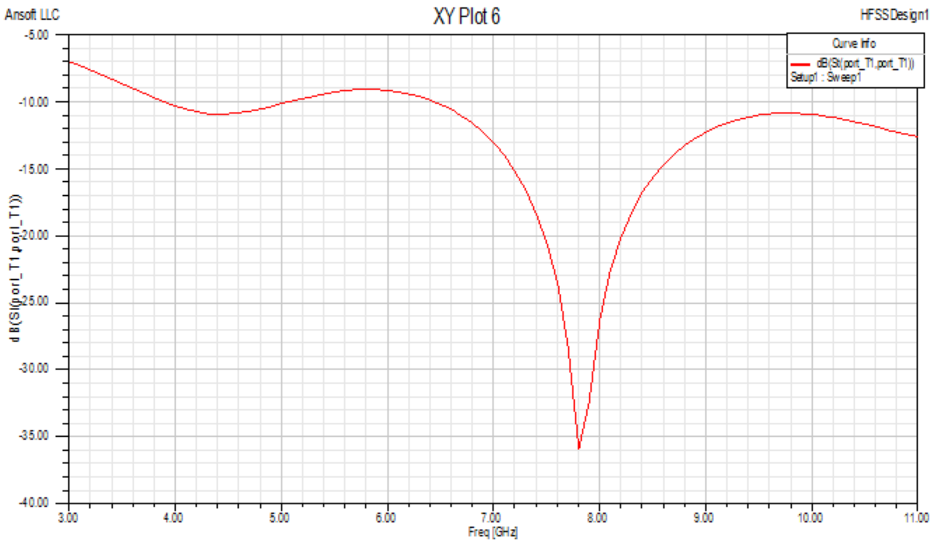

Figure 3.21: Plot of Return Loss (S_{11}) of Second Test (One Slot) Antenna with Finite Ground Plane

bandwidth achieved is 1.4 GHz, and the maximum value of the return loss is -36 dB. A single sharp resonance at 8 GHz is also obtained.

The return loss plot of the simulation result with three slots antenna is shown in the Figure 3.22. In this case the resonance occurs at 8.5 GHz of frequency with a return loss of -33 dB, while the bandwidth is increased to 2.5 GHz. Though with full ground the Ultra Wide Band specification is met, but for satellite communication two distinct resonances are required.

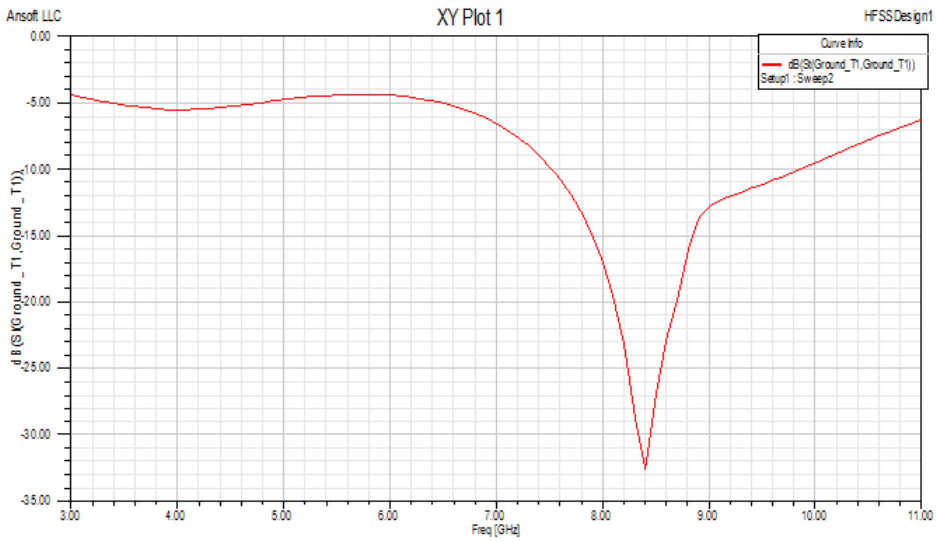

Figure 3.22: Plot of Return Loss (S_{11}) of Third Test (Three Slots) Antenna with Finite Ground Plane

3.11 Effect of Partial Ground Plane on the Performance of Antenna

Conventional microstrip antennas have larger ground plane. The effect of the ground plane is to confine the waves and hence influence the directivity of the antenna. The higher directivity with the finite ground plane confined the radiation and causes the less bandwidth. The dimension of the ground plane has a direct effect on the variation of the input impedance and resonant frequency. The partial plane reduces the directivity and hence the radiation of the antenna tends to become less directional. The resonant frequency also got slightly shifted with ground plane truncation. For a given substrate the input impedance varies widely [95] with the ground plane dimensions. The surface wave loss is high when the ground plane dimension is approximately equal to half of the resonant wavelength and low at three quarter of the resonant wavelength.

The simulation with HFSS is carried out to study the effect of partial ground plane on the performance of the antenna. Simulation is done at various length of the ground plane by keeping the width equals to width of substrate. The best performance is achieved at 11 mm length of the ground plane. The variation of the return loss as a function of frequency, for the three test antenna having partial ground plane configuration, is plotted in Figures 3.23 to 3.25.

Figure 3.23 is the simulation result with first antenna without any slot but with four notches. Figure 3.23 reveals that the antenna exhibit two resonance peaks at 4.8 GHz and 7.2 GHz of frequency with a bandwidth of 5.4 GHz. The maximum return loss of -35 dB is obtained at 7.2 GHz of frequency.

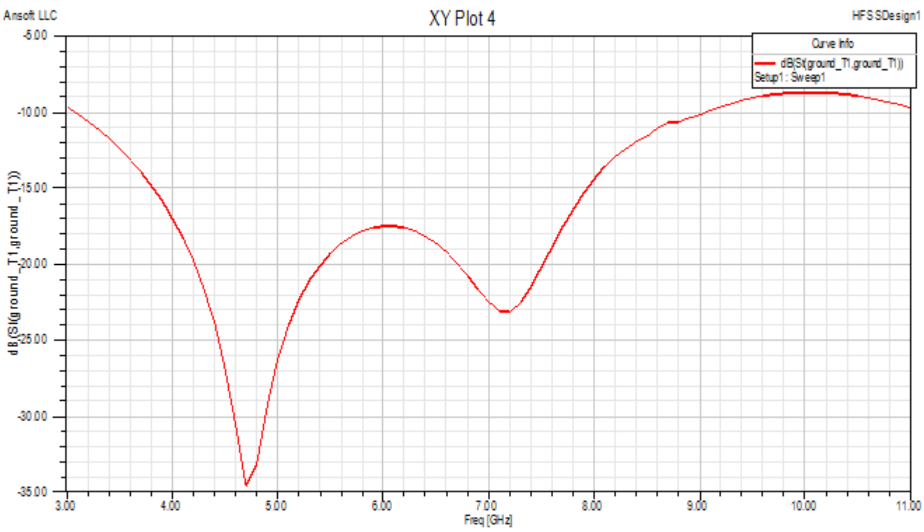

Figure 3.23: Plot of Return Loss (S_{11}) of First Test (Plain) Antenna with Partial Ground Plane

Figure 3.24 is the simulation result of the second test antenna loaded with one slot and four notches. Figure3.24 discloses that the antenna exhibit two resonance peaks at 4.8 GHz and 7.2 GHz of frequency with a bandwidth of 4.3 GHz. The maximum return loss of -25 dB is obtained at 4.8 GHz of frequency.

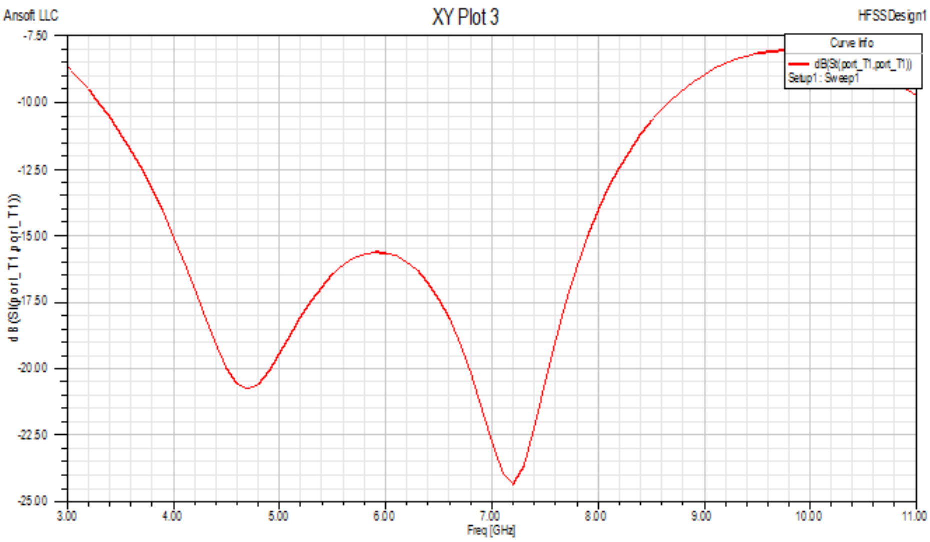

Figure 3.24: Plot of Return Loss (S_{11}) of Second Test (One Slot) Antenna with Partial Ground Plane

The simulation result of the third test antenna loaded with three slots and four notches is shown in Figure 3.25. This Figure reveals that the antenna exhibit two resonance peaks at 5.2 GHz and 7 GHz of frequency. The best performance is obtained in this case both in terms of return loss and bandwidth. The two resonance peaks are -40 dB and -50 dB respectively. The bandwidth attained is 5.9 GHz. In all the three cases not only the bandwidth becomes high, but two distinct resonance frequencies are also obtained. The Table 3.4 shows the summarized result of the effect of ground plane on the antenna performance. The final dimensions of three test antennas are shown in the Table 3.5.

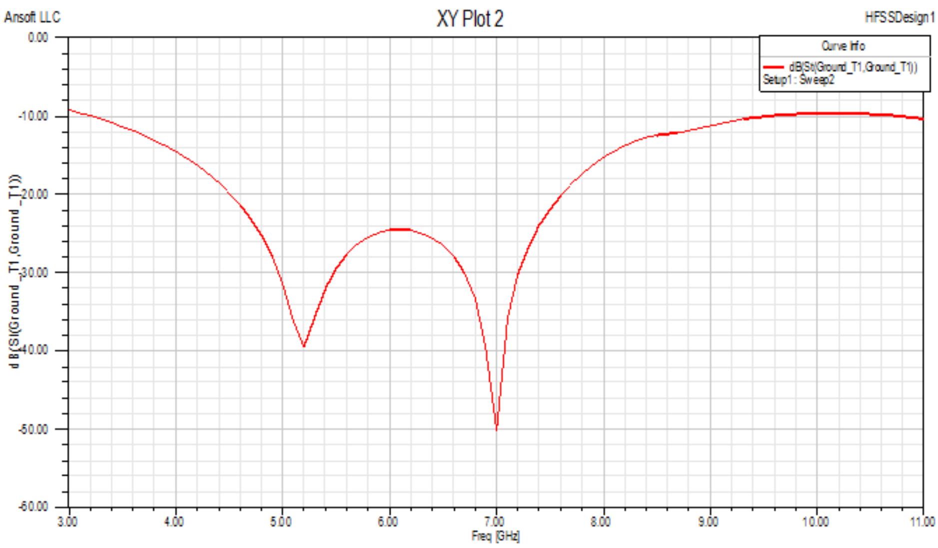

Figure 3.25: Plot of Return Loss (S_{11}) of Third Test (Three Slots) Antenna with Partial Ground Plane

Test Antenna	**Configuration**	**BW**	**%BW**	**Return loss**
First	No slot but 4 notches	5.4 GHz	91	-35 dB
Second	One slot & 4 notches	5.3 GHz	89	-25 dB
Third	3 slots & 4 notches	5.9 GHz	94	-50 dB

Table 3.4: Effect of Partial Ground Plane on the Performance of the Antenna

The simulated diagrams of the three test antenna configurations are shown in the Figures 3.26, 3.27 and 3.28.

Parameter	Dimension of First Test Antenna	Dimension of Second Test Antenna	Dimension of Third Test Antenna
Length of Patch	12 mm	12 mm	12 mm
Width of patch	16 mm	16 mm	16 mm
Height of substrate	1.6 mm	1.6 mm	1.6 mm
Length of feed line	12 mm	12 mm	12 mm
Width of feed line	4 mm	4 mm	4 mm
Length of slot	-	10 mm	10 mm
Width of slot	-	2 mm	2 mm
Distance of slot	-	3.75 mm	1.75 mm, 6 mm & 8.75 mm
Length of Notch	0.5 mm	0.5 mm	0.5 mm
Width of notch	2 mm	2 mm	2 mm
Length of substrate	29 mm	29 mm	29 mm
Width of substrate	26 mm	26 mm	26 mm
Length of ground plane	11 mm	11 mm	11 mm
Width of ground plane	26 mm	26 mm	26 mm

Table 3.5: Final Dimension of the Three Test Antennas

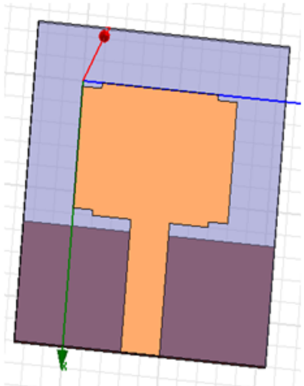

Figure 3.26: Simulated Diagram of First Test Antenna in HFSS

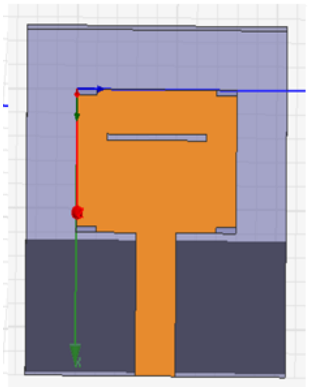

Figure 3.27: Simulated Diagram of Second Test Antenna in HFSS

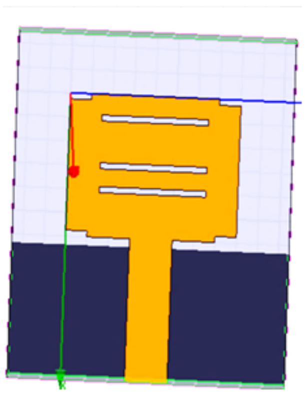

Figure 3.28: Simulated Diagram of Third Test Antenna in HFSS

3.12 Chapter Summary

This chapter exploited the broadening of the microstrip antenna. For this work the rectangular planer structure of the microstrip antenna is chosen. The various means for the broadening of the rectangular planer structure is cited. This chapter also featured the all necessary equations required in the design of the specific antenna. The broadening of the antenna is done by using the methods mostly suitable for the simpler and planer structure. The designing is accomplished by both Advanced Design Software and High Frequency Structure Simulator software. ADS software is used for the optimization of width of the patch, height of the substrate, dimension of the slots, position of the slots, numbers of slots, dimension of the notches and the number of the notches. The optimization of the dimension of the substrate and the ground plane is done by the HFSS software. The combined results from the two simulation software are taken as final design parameter. Three different antennas are proposed which are now referred as test antenna. The first test antenna is without slot, while rests of the two are encumbered with one slot and three slots respectively. The dimensions of the patch, substrate, slot, notch and the ground plane is kept constant for the entire three test antenna to validate the design.

Chapter 4

Fabrication & Testing

The post validation of the design with the antenna design software tools is further validated by the actual hardware fabrication.

4.1 Methods of Fabrication

The various methods used for the fabrication of the microstrip antenna are discussed below:

4.1.1 Chemical Etching

In this method initially the substrate board is coated with photo-resist material. Air brush technique is applied for the coating. By this means the amount of photo-resist material, used for the coating, is saved. But a thin and uniform coat is difficult to obtain by brush coating. Hence to get rid of this, a standard spinner method is used for the uniform and thin coating. In the spinning method the thickness of the coat is from 1.0 to 1.5 microns as compared to 4 to 5 micron while apply the brush method. After spinning, the substrate board is heated to a temperature of 100 degree Celsius for about a minute for drying the coat. The printed mask of the antenna geometry is then paced over the board. The printed mask is the image of the .dxf file of the simulation software. Then substrate board is then exposed in ultra-violet rays for about 2 minutes. Once the photo-resist was removed, the substrate board is rinsed thoroughly with water and dried. In the last stage the substrate board is placed in ferric chloride solution for etching. After proper etching, the substrate board is rinsed with acetone to remove any unwanted photo resist material left.

4.1.2 Photo Lithography

In this method [96] initially a computer aided design of the antenna planer geometry is made and a negative mask of the antenna geometry generated is printed on a transparent sheet. The proper substrate with copper metallization on which the desired patch is etched is selected. It may be single or double sided depending on the antenna geometry.

The suitable dimension of the substrate is cut and is properly cleaned with acetone to make it free from any short of impurities. A thin layer of negative photo resist solution, diluted with equal quantity of thinner, is coated on copper surfaces by using spinning technique. The patch is then left to be dried properly. The mask is then placed onto the photo resist and it is exposed to ultra violet rays of light. A proper exposure to the ultra violet light transformed the layer of photo-resist material into a hard one during its treatment with developer solution. The whole substrate board is then dipped in dye ink solution for a clear view of the hardened photo resist portions as marked on the copper coating. Finally the substrate board is thoroughly washed in water. A solution of ferric chloride is used to get the proper required antenna geometry on the selected substrate by properly etching the unwanted copper portion. After few minutes the ferric chloride solution dissolves the copper parts except the hardened photo resist layer.

This process is done during the developing phase. Any etchant found on the board is removed by thoroughly rinse it in running water. Lastly the acetone solution is again used to cleaned the board for removing the hardened photo resist.

4.1.3 Computer Controlled Coordinatograph

This process involve the making of the mask of the required antenna geometry by using coordinatograph. The method fixes [97] the single or double copper metallized suitable substrate to the stage in coordinatograph and the board of the substrate is covered by an elastic varnish. The coordinatograph is controlled by microcontroller connected to the computer through the standard interface. It is implemented as a desktop apparatus controlled by the Intellicad software tool. The geometry of the designed microstrip antenna is loaded in a form of Gerber file. If the dimension of any portion of the antenna is lower than 100 micro meters, then semi-automatic photo plotter is used for the mask making. The semi-automatic photo plotter can be able to work up to 40 micro meters. Either coordinatograph or the photo plotter receives the Gerber file format. Therefore before the process of the mask making, the antenna software file is exported and converted into the Gerber file. The mask is the replica of the required antenna geometry. After that the fabrication of the antenna is done on the substrate.

In this present work, the fabrication of the antenna is done by using the coordinatograph method. The work is carried out at the IC design lab of the Department of Microwave, Centre for Advance Research in Electronics (CARE), IIT Delhi.

A mask of the three slot antenna is shown in the Figure 4.1.

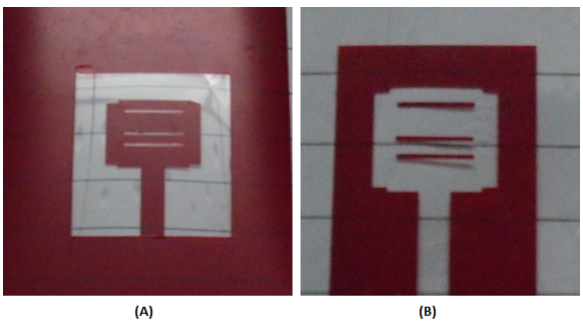

Figure 4.1: Mask of Test Antenna Prior to Final Fabrication

The final images of the patches of three test antennas are shown in the Figure 4.2, 4.3 and 4.4.

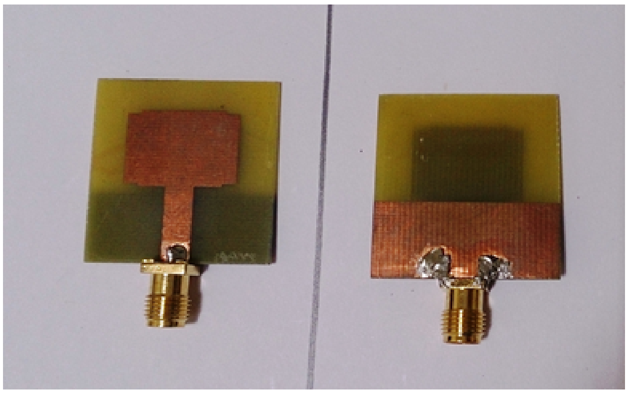

Figure 4.2: Fabricated Image of Front and Back of First Test Antenna

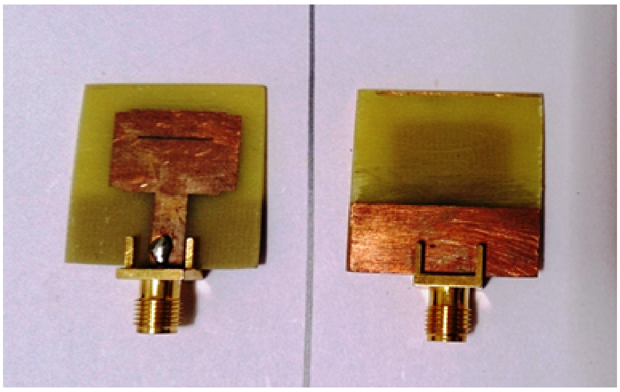

Figure 4.3: Fabricated Image of Front and Back of Second Test Antenna

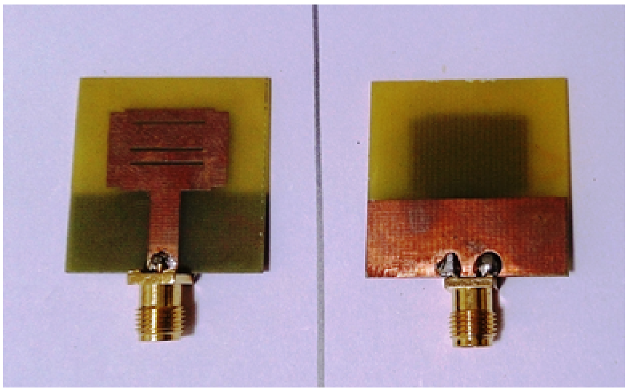

Figure 4.4: Fabricated Image of Front and Back of Third Test Antenna

4.2 Testing of the Antenna

Testing of the antenna is done using Network Analyzer.

4.2.1 Network Analyzer

A Network analyzer is an advanced and sophisticated instrument. This instrument is used [98] to measure the network parameters of the device. it commonly measures the S-parameter at high frequencies since the reflection and transmission of the signals are easy to measure. The network analyzer is capable of performing a quick and accurate measurements in both time and frequency domain. It has been widely used by radio frequency design laboratories. It is basically used for characterizing or measuring the response of devices or antennas at all radio frequencies. The device finds extensive used in the microwave frequencies. However certain analyzers cover lower frequencies down to few Hz. It is used for measuring a variety of components ranging from frequency sensitive networks to radio frequency oriented device along with filters, transistors and mixers. By measuring the response of device or antenna the characterization is done and from this the working of the device is judged for which it is intended.

4.2.2 Types of Network Analyzer

There are three types of RF network analyzers within the broad scope. All these are used to measure the radio frequency parameters of the devices but in different ways:

Scalar Network Analyzer (SNA)

It is a type of network analyzer that is used for measuring the amplitude properties or scaler properties of the device. Therefore it is the simplest of all network analyzer. It works just as a spectrum analyzer in combination with a tracking generator. When these two are used together, their operation is electrically closely linked. The tracking generator generators a swept signal having the same frequency as the spectrum analyzer is receiving. Therefore if the output from the tracking generator is connected to the input of the spectrum analyzer, then a constant line is viewed across the screen of the analyzer. This line indicates the amplitude of the tracking generator output. If a device is placed between these two, then the spectrum analyzer will note any variation in the amplitude. The response of the device will change it according to the frequency and the spectrum analyzer will display this response. Thus this scalar network analyzer is very useful in measuring the amplitude response of the device.

Vector Network Analyzer (VNA)

This category of the network analyzer is a more useful analyzer. It is capable of measuring more parameters about the device. Not only does it measure the response in amplitude, but it measures the phase also. So this analyzer is also called a gain-phase meter or an Automatic Network Analyzer. This analyzer is consisting of a test system for the characterization of the device in terms of network scattering parameters or S parameters. The information provided by the vector network analyzer is used to ensure that the design of the device is optimized to get the best performance.

Large Signal Network Analyzer (LSNA)

This network analyzer is a highly specialized form. It is used to investigate the characteristics of devices under large signal conditions. It provides a full analysis of its operation by measuring the harmonics and non-linearity of a device. This device is mostly used in devices operating in microwave frequencies. Hence it is earlier called as Microwave Transition Analyzer.

4.2.3 Testing of the Test Antennas

The Vector Network Analyzer (VNA) is used in the testing of the three fabricated test antenna for measuring the magnitude and phase of the S-parameters. The microcontroller based system is used to measure two port network parameters and the in-built signal processor analyses the data. Finally the result is displayed in many plot formats. Usually a network analyzer is consisting of microwave source, S-parameter test set, signal processor and a display unit. This equipment is used in a wide range of frequencies ranging from 10 MHz to 50 GHz. for the testing of the antenna it provides exceptional result with fast measurement. It normally measured a test point in less than 25 μs. It has the facility to set the frequency in either step mode or ramp mode as per the requirement of the measurement accuracy. During the testing of the antenna, the test antenna is connected to the two port S-parameter set unit. The incident and reflected signals at the port are down converted to intermediate frequency of the magnitude of 20 MHz before being fed to the detector. In the processing unit it is again down converted to lower frequency. The two signals are processed suitably, and the result is displayed in terms of the magnitude and phase information. The test antenna is connected to the instrument through a matched system bus. The displayed result can be saved in a text format by the in-built data acquisition measurement system. The whole process is operated smoothly by using a computer interface system.

The Figure 4.5 shows the test antenna connected to the test port of the network analyzer for testing. The passive parameters of all three test antennas are tested at the Department of Microwave, Centre for Advance Research in Electronics (CARE), IIT Delhi.

Figure 4.5: Image of Test Antenna on the Test Bench of the VNA

The display of the showing the return loss pattern of the test antenna is shown in Figure 4.6 along with a clearer and close view of the display unit in Figure 4.7.

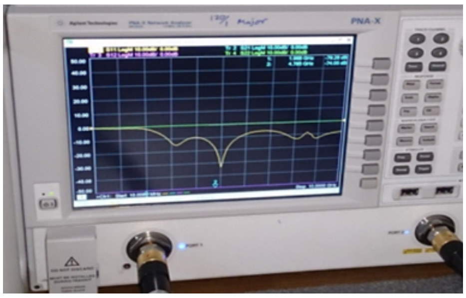

Figure 4.6: Image of the Front panel and Screen of the VNA

Figure 4.7: Return loss pattern of Third Test Antenna on the Display of VNA

4.3 Chapter Summary

The various methods used in the fabrication of the microstrip antenna are concisely cited in this chapter. The parameters of the antenna are commonly characterized by the network analyzer. A brief review note on the use and types of network analyzer is also reported here. The mask of the antenna from the fabrication methods and the images of the all test antennas are cited.

Chapter 5

Results and Discussion

Corroboration is required among the results obtained from the simulation and experimental. To validate the work, the comparison of simulated results and measured results are made for the following active and passive parameters of the test antennas.

i. Return Loss

ii. VSWR

iii. Through Power

iv. Gain

v. Radiation Efficiency

vi. 3-Dimensional Radiation Pattern

5.1 Comparison of Simulated and Measured Parameters of the Test Antennas

This section presents the verification and discussion of the simulated and measured results for the three test antennas.

5.1.1 Verification and Discussion of First Test Antenna

This first test antenna has no slot and is only loaded with four notches at the corner of the edges. The first comparison is presented in Figure 5.1.

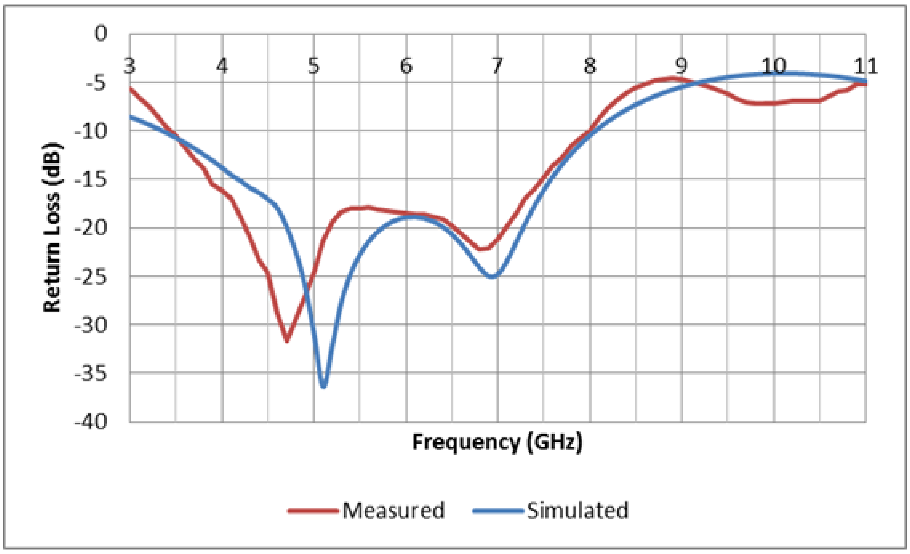

Figure 5.1: Comparison of Return Loss (S_{11}) of First Test Antenna

The Figure 5.1 reveals that the simulation and the measured result are very much close to each other within the entire band of the frequency. The maximum return loss of -31 dB and -36 dB are obtained in the measured and simulation results respectively. Further it depicts that the test antenna is having the return loss greater than -10 dB in between 3.4 GHz to 8.1 GHZ and hence bandwidth of 4.7 GHz, which is three times more than the specified minimum bandwidth of the Ultra Wide Band specification. There are two distinct peaks that are wide separated. The two peaks are at different return loss magnitude. The VSWR curves with respect to the frequency are plotted in the Figure 5.2.

The measured and simulated results for the through power are plotted in the Figure 5.3. It is clear from the Figure 5.3 that the through power is more than 90% within the antenna operating bandwidth, and has a maximum value of 98% at the peak resonance.

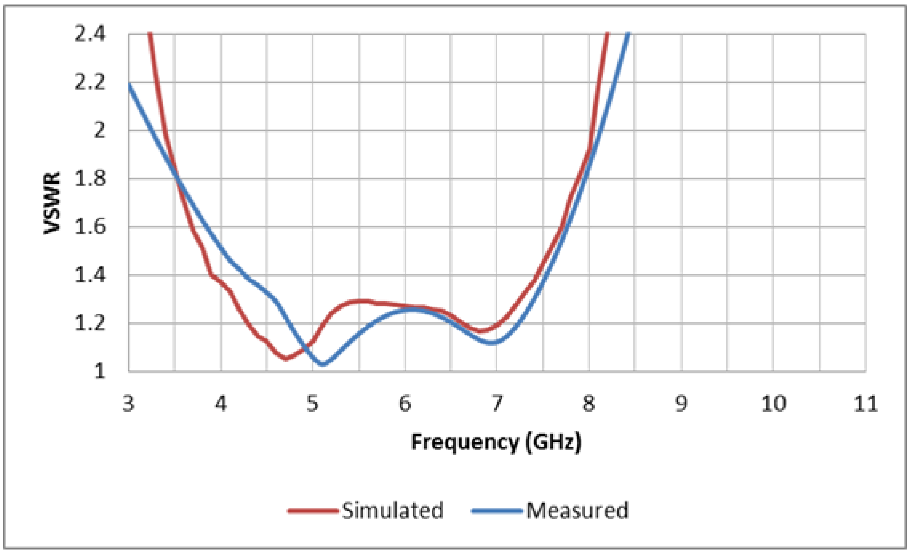

Figure 5.2: Comparison of VSWR of First Test Antenna

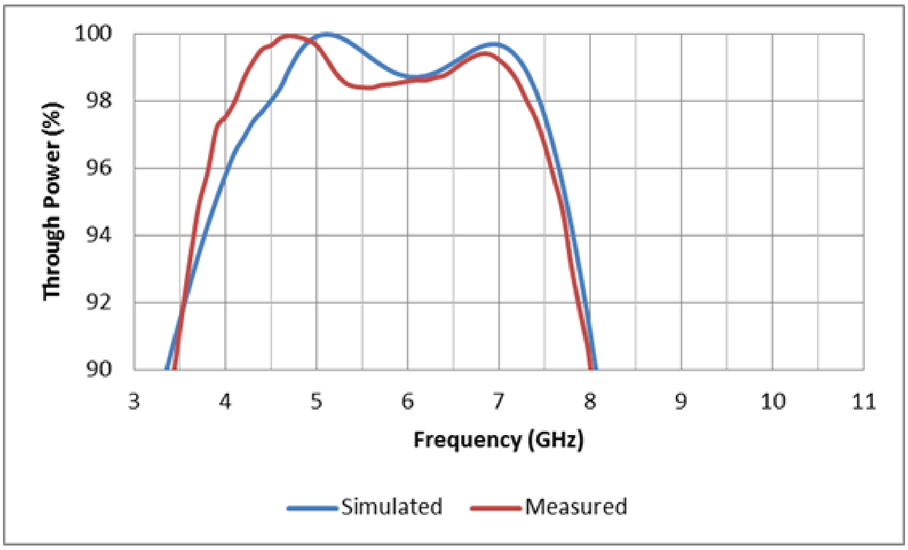

Figure 5.3: Comparison of Through Power of First Test Antenna

The simulation result of the total gain, realized gain and the directivity of the first test antenna is plotted in the Figure 5.4. At the peak resonance frequency, the maximum gain and the directivity obtained by this test antenna is 1.06 dB and 1.14 dB respectively.

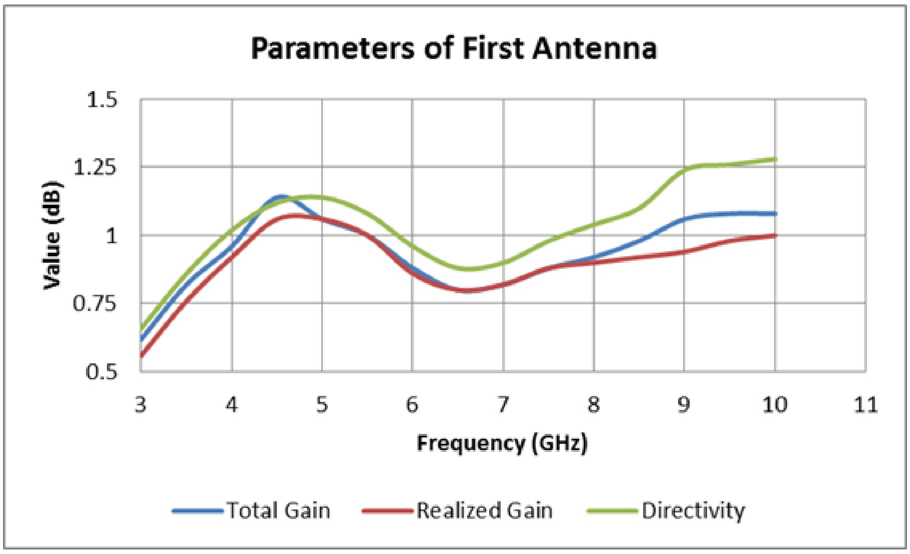

Figure 5.4: Plot of Active Parameters of First Test Antenna

The simulated radiation pattern in the E-plane of the first test test antennas are shown in the Figure 5.5. In this case the radiation pattern is very uniform and resembles that of a dipole pattern. This test antenna has no slot. Hence the pattern exhibits a uniform radiation.

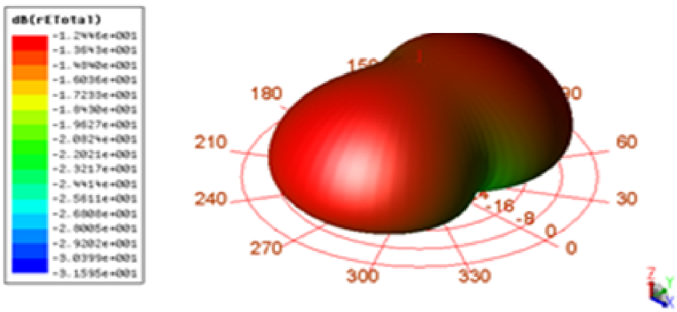

Figure 5.5: E-Plane Radiation Pattern of the First Test Antenna

5.1.2 Verification and Discussion of Second Test Antenna

The comparison between the simulation and measured results for the second test antenna are presented below. The second test antenna is loaded with a single slot and four notches. The return loss is compared in Figure 5.6 in the frequency range from 3 GHz to 11 GHz.

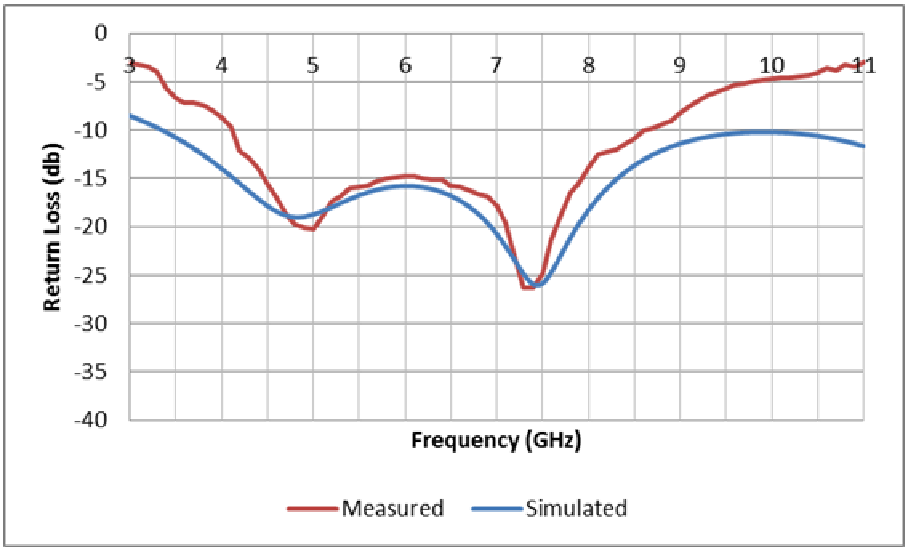

Figure 5.6: Comparison of Return Loss (S_{11}) of Second Test Antenna

Figure 5.6 reveals that the return loss of lower than -10 dB from 3.3 GHz to 9.5 GHz in the simulation, whereas in the measured result, it is from 4.1 GHz to 8.6 GHz. The fabricated antenna achieved a bandwidth of 4.5 GHz, and is well within the Ultra Wide Band range. In both the simulation and measured value two distinct resonance peaks are obtained. The comparison of the simulation and measured results for VSWR is shown in Figure 5.7. It is evident form the plot that the VSWR is falling below 2 in the Ultra Wide Band region. The minimum value of VSWR obtained for the fabricated antenna is 1.12.

Comparison for the through power of the antenna is made in Figure 5.8. Within the Ultra Wide Band region, the through power is achieving more

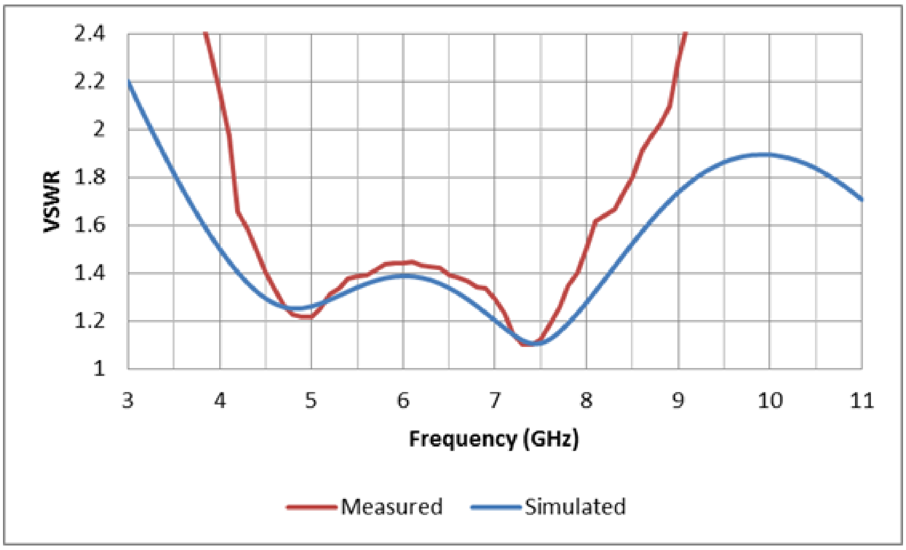

Figure 5.7: Comparison of VSWR of Second Test Antenna

than 90%. The maximum power at the peak resonance is nearly 98%. This indicated that the second test antenna has a very good impedance matching within the range of frequencies.

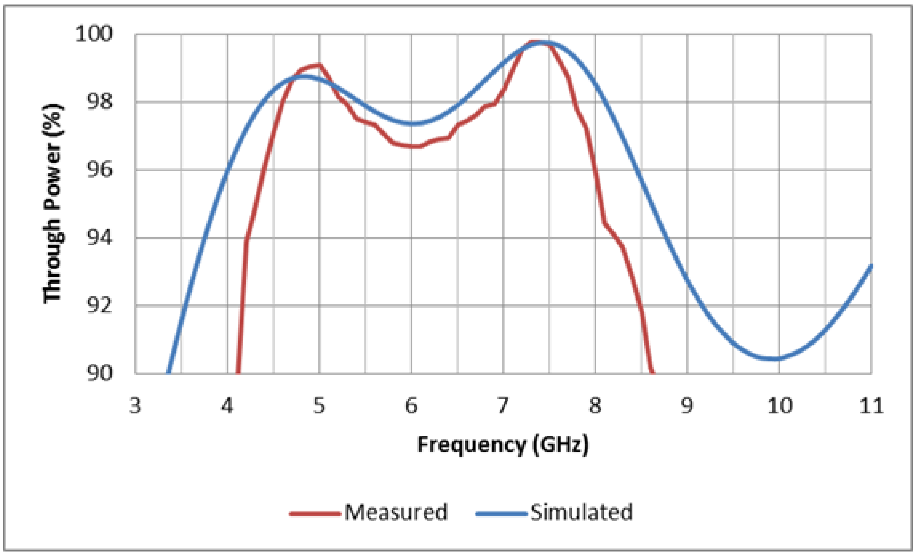

Figure 5.8: Comparison of Through Power of Second Test Antenna

The simulation result of the total gain, realized gain and the directivity of the second test antenna is plotted in the Figure 5.9. At the peak resonance frequency, the maximum gain and the directivity obtained by this test antenna is 1.08 dB and 1.18 dB respectively.

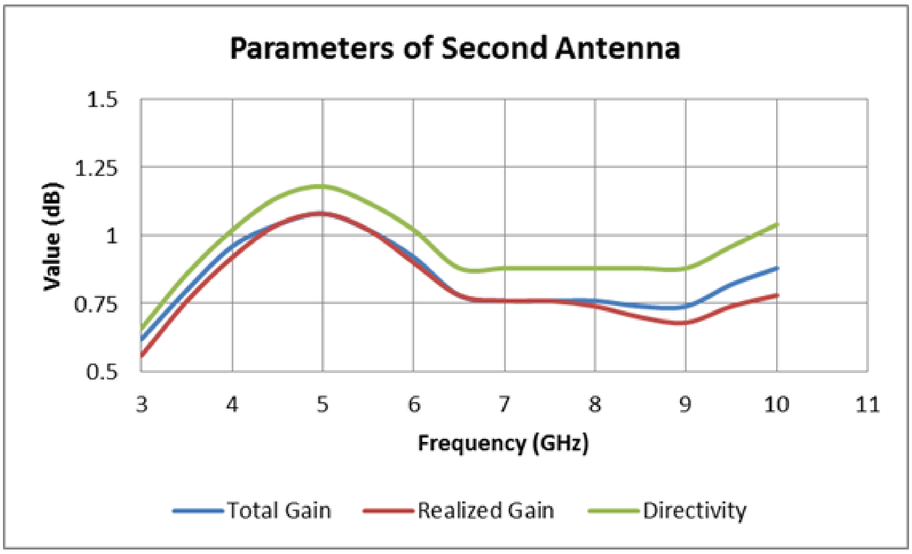

Figure 5.9: Plot of Active Parameters of Second Test Antenna

The simulated radiation pattern in the E-plane of the second test test antenna is shown in the Figure 5.10. The second test antenna has one slot near its non- radiating edge. Its radiation pattern is very similar to first one, but the energy in the z-direction is not uniformly distributed as the first test antenna.

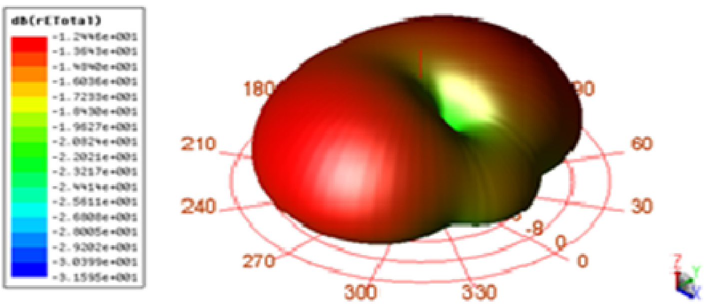

Figure 5.10: E-Plane Radiation Pattern of the Second Test Antenna

5.1.3 Verification and Discussion of Third Test Antenna

The third test antenna is loaded with three slots and four notches. The comparison between the simulation and measured results for the return loss is presented in the Figure 5.11. It clearly depicts the two well wide placed distinct resonance peak of the same magnitude of the return loss. For this antenna, the measured result is also in close proximity of the simulation result. The maximum value of the return loss is -40 dB. The frequency range for this fabricated test antenna is from 4.1 GHz to 9.2 GHz below -10 dB of the return loss. Therefore the bandwidth of the test antenna is 5.1 GHz. This antenna achieved the maximum bandwidth and return loss among the three.

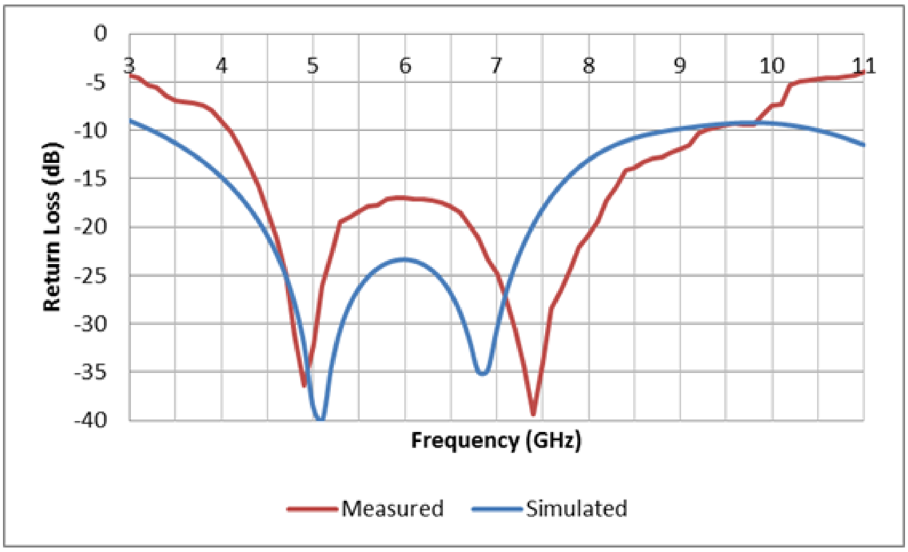

Figure 5.11: Comparison of Return Loss (S_{11}) of Third Test Antenna

The comparison of simulation result and the measured result for VSWR is shown in Figure 5.12. This test antenna attained the minimum VSWR of 1.02 and 1.05 at the two distinct resonance frequencies. The VSWR is less than 2 over the entire operating bandwidth. The through power results are shown in Figure 5.13. From the Figure 5.13, it is observed that the through power is more than 90% in the entire range of operating bandwidth, and

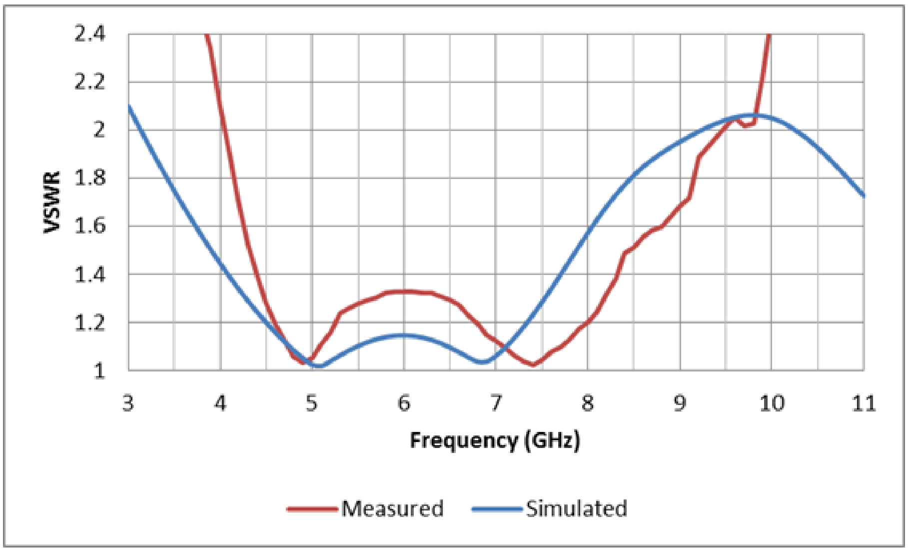

Figure 5.12: Comparison of VSWR of Third Test Antenna

it achieved more than 98% in most of the operating range.

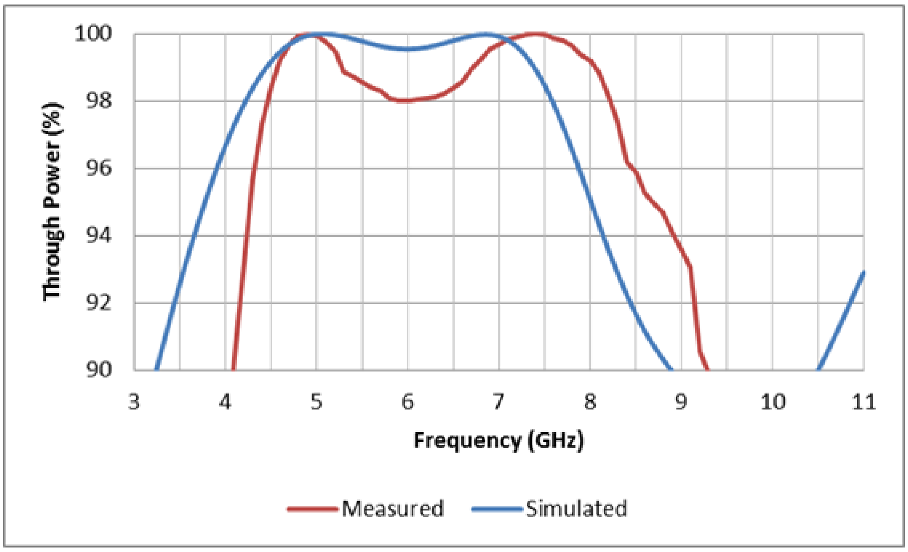

Figure 5.13: Comparison of Through Power Third Test Antenna

The simulation result of the total gain, realized gain and the directivity of the third test antenna is plotted in the Figure 5.14. At the peak resonance frequency, the maximum gain and the directivity obtained by this test antenna is 1.12 dB and 1.26 dB respectively.

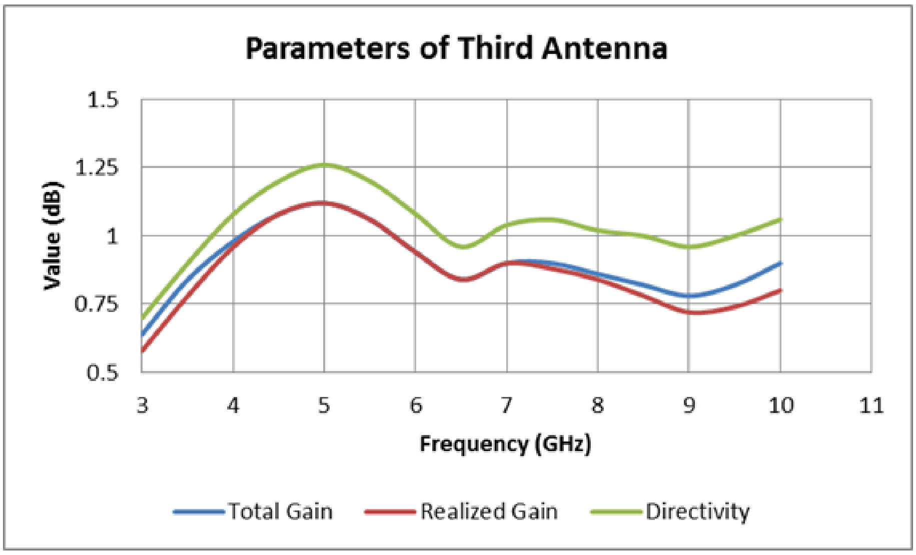

Figure 5.14: Plot of Active Parameters of Third Test Antenna

The simulated radiation pattern in the E-plane of the third test antenna is shown in the Figure 5.15. The pattern in this case shows the sharp radiation pattern. Its radiation pattern is exactly as that of a dipole antenna. This test antenna has three uniform slots, therefore the radiation along the x-axis of the radiation is very sharp making the pattern very well distributed. The bandwidth and the return loss of the third test antenna is the best amongst the three, hence the radiation pattern of the third test antenna is the most uniformly distributed along the direction of radiation.

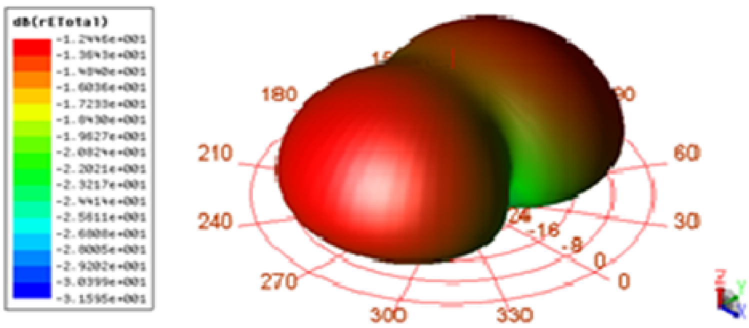

Figure 5.15: E-Plane Radiation Pattern of the Third Test Antenna

As per the requirement of the Ultra Wide Band specification, the specified gain of an Ultra Wide Band antenna is less than 5 dB. Though our proposed antenna gain is less than 5 dB, but the gain is not up to the mark. This is because the aperture of the antenna is very small and gain is directly proportional to the aperture. All the three antennas achieved a sharp first resonance near 5 GHz and consequently an increase in the gain and directivity is obtained near 5 GHz of frequency for the three proposed antenna. After 5 GHz of frequency the gain and directivity reduces, but again shows an increases near the second peak resonance which is near to 8 GHz of frequency. The radiation efficiency of the three test antennas over the Ultra Wide Band range of frequencies is plotted and it is shown in the Figure 5.16.

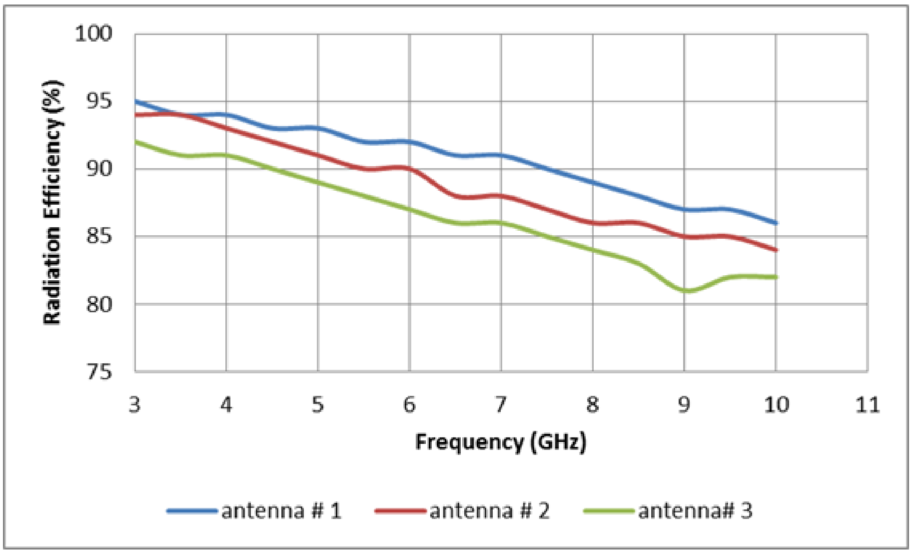

Figure 5.16: Plot of Radiation Efficiency of the Three Test Antennas

Radiation efficiency is calculated using the gain and directivity of the antenna. Since the gain and directivity all three proposed antennas are closely matching each other over the entire frequencies, therefore a very efficient radiation is achieved as observed in the Figure 5.16. On an average this efficiency is near to 90%, which is quite high with respect to the 75% mark as stated in the Ultra Wide Band specification.

5.2 Comparison of Results of the Test Antennas and Ultra Wide Band Specification

A comparison of the results of the three test antennas along with the Ultra Wide Band specification is tabulated in Table 5.1.

Parameter	**UWB specification**	**First Test Antenna**	**Second Test Antenna**	**Third Test Antenna**
Frequency (GHz)	3.1 - 10.4	3.4 - 8.1	4.1 - 8.6	4.1 - 9.2
Bandwidth	$>$ 1.5 GHz	4.7 GHz	4.5 GHz	5.1 GHz
% Bandwidth	$\geq$ 25	75	64	85
Return loss	$\leq$ -14 dB	-36.1 dB	-26.3 dB	-39.3 dB
VSWR	$<$ 2	1.05	1.12	1.02
Radiation efficiency	$>$ 75%	86%-95%	84%-94%	82%-92%

Table 5.1: Comparison of the Results of the Three Test Antennas

It is depicted form the Table 5.1, that the performance parameter of the three test antennas is well asserting the UWB specification. Test antenna 3 is presenting the best results among the three in terms of bandwidth, return loss and VSWR.

5.3 Determination of Impedance of the Patch using Transmission Line Analysis

There are two ways of modelling the parameters of the microstrip antenna. One is transmission line method, which is mostly used to find the impedance. The second method is the cavity method. The quality factor is determined by this method, which account for the theoretical calculation of the bandwidth.

The Transmission Line Model is easy to implement and versatile method. This method [99] is mostly suitable for rectangular microstrip structure. Though this method lacks the accuracy of the result, but provides a good insight and the field distribution for all TM modes. This method is mostly used in the calculation of the impedance.

The equivalent circuit of the whole patch as resembled as two radiating slots [100] is shown in Figure 5.17. The antenna behaves as an open circuit with a section of the terminated plate terminated at both the ends.The two slots acts as a parallel RC circuit connected by the patch is like a transmission line connecting them. The length of the transmission line is L_{eff} and the characteristic impedance of the line is Z_C. The terminals at each ends are represented as normalized admittance Y. The admittance Y is given

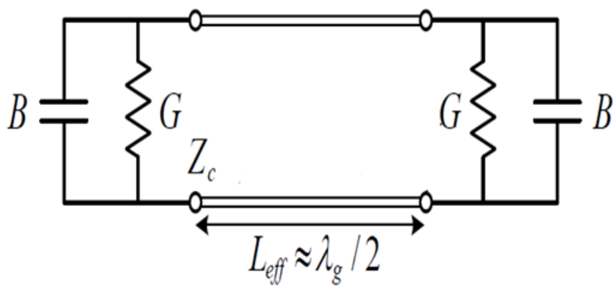

Figure 5.17: Simplified Equivalent Circuit Representation of The Microstrip Antenna using Transmission Line Model

as:

$$Y = G + jB \tag{5.1}$$

The radiation loss, R, is equal to the reciprocal of conductance, G. Whereas the capacitance of the slot is equal to $B/j\omega$.
The input admittance of the circuit is given as:

$$Y_{in} = Y_c|\frac{Y_L + jY_c tan(\beta L)}{Y_c + jY_L tan(\beta L)}| \tag{5.2}$$

And the input impedance, $Z_{in} = 1/Y_{in}$

For a normalized value of $\beta_L = \pi$, $Z_{in} = Z_L$. That means both the line impedance and the input impedance are of the same value at this extreme case of optimization. The normalized value of the characteristic impedance of the microstrip line feed of width, W_m, is given ($W_m < \lambda_0$) as:

$$Z_c = \frac{120\pi}{\sqrt{\epsilon_{eff}}}\{\frac{W_m}{h} + 1.4 + 0.67ln(\frac{W_m}{h} + 1.45)\}^{-1} \tag{5.3}$$

In our work the width of the microstrip line is taken as 4 mm, the height of the substrate as 1.6 mm and the dielectric constant of the epoxy substrate as 4.4. Putting these value in the above equation, the characteristic impedance of the microstrip feed line comes to be 40.24 Ω. Since, the source is having an impedance of 50 Ω, therefore the input impedance of the patch at the junction is calculated as 32.39 Ω.

From the classical waveguide theory, the impedance is given as:

$$Z = \frac{120\pi}{\sqrt{\epsilon_{eff}}} \text{ x } \frac{h}{W} \tag{5.4}$$

The impedance of the patch is calculated to be 39.63 Ω.

5.4 Determination of Q-factor and Bandwidth from Cavity Method Analysis

Inspite of the complexity, this approach gives a good insight into the result. The Q-factor is determined by this method. In this method the antenna is treated as cavity.

But treating the microstrip antenna only as cavity, the radiation from it cannot be represented. Since an ideal loss free cavity shows no radiation. The input impedance of this loss free cavity is purely reactive. Therefore a loss mechanism is needed to introduce which account for the radiation. This introduced loss is termed as effective loss tangent. The effective loss tangent, l_e, is related to the Q-factor of the microstrip patch. The relation between the effective loss tangent and Q-factor is given as:

$$l_e = \frac{1}{Q} \tag{5.5}$$

This Q-factor determines the bandwidth of the microstrip patch antenna. The relationship between Q-factor and bandwidth is given as:

$$\text{Bandwidth} = \frac{\text{Resonant frequency } (f_r)}{\text{Q Factor}} \tag{5.6}$$

Therefore, the bandwidth is theoretically determined by first determining the total Q-factor of the antenna.

The total quality factor (Q_T) is the combined form [101] of the quality factor due to radiation (Q_r), the quality factor associated with conductor loss (Q_c), the quality factor due to dielectric loss (Q_d), and the quality factor associated with the surface wave (Q_s). The Q-factor in terms of these is given as:

$$\frac{1}{Q_T} = \frac{1}{Q_r} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_s} \tag{5.7}$$

or,

$$Q_T = \left[\frac{1}{Q_r} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_s}\right]^{-1} \tag{5.8}$$

The quality factor associated with the dielectric loss, Q_d, is directly related to the loss tangent of the material of the substrate, and is given as:

$$Q_d = 2\pi f\left(\frac{\epsilon_0\epsilon_r}{\sigma_d}\right) = \frac{1}{tan\delta} \tag{5.9}$$

The quality factor associated with the conductor loss of the conducting material is given as:

$$Q_c = 2\pi f\left(\frac{\epsilon_s}{P_c}\right) \tag{5.10}$$

Here, P_C is the power loss due to the conductivity of the patch material, and is given as:

$$P_c = R_s \int \mid H_s \mid^2 ds = h\sqrt{\pi f \mu_0 \sigma_c} \tag{5.11}$$

And the term ϵ_S , is given as:

$$\epsilon_s = \frac{1}{2}\int \epsilon_0\epsilon_2 \mid E_z \mid^2 dv = \epsilon_0\epsilon_r V_0^2 (\frac{L \text{ x } H}{4\pi}) \tag{5.12}$$

The quality factor due to the radiation loss is given as:

$$Q_r = 2\pi f\left(\frac{\epsilon_s}{P_r}\right) \tag{5.13}$$

The power loss due to the radiation P_r, is given as:

$$P_r = \frac{1}{2}\sqrt{\frac{\epsilon_0}{\mu_0}}\int\int \mid E_\theta \mid^2 + \mid E_\phi \mid^2 .r^2 \text{Sin}\theta \text{d}\theta \text{d}\phi \tag{5.14}$$

Putting the value of P_r and ϵ_S and simplifying, we get:

$$Q_r = \frac{3}{16}\frac{\epsilon_0}{p}\frac{\epsilon_{eff}}{C_1}\frac{L}{W}\frac{\lambda_0}{h} \tag{5.15}$$

p and c_1 are constant. The value of p $\approx$ 1 (for W and $L < \lambda_0$).The value of c_1 is given as:

$$c_1 = 1 - \frac{1}{\mu_r \epsilon_r} + \frac{215}{(\mu_r \epsilon_r)^2} \tag{5.16}$$

Quality factor associated with the surface loss is not taken into account for this work because of its complex computational parameter.

A plot showing the total quality factor and other quality factors associated with this is shown in the Figure 5.18.

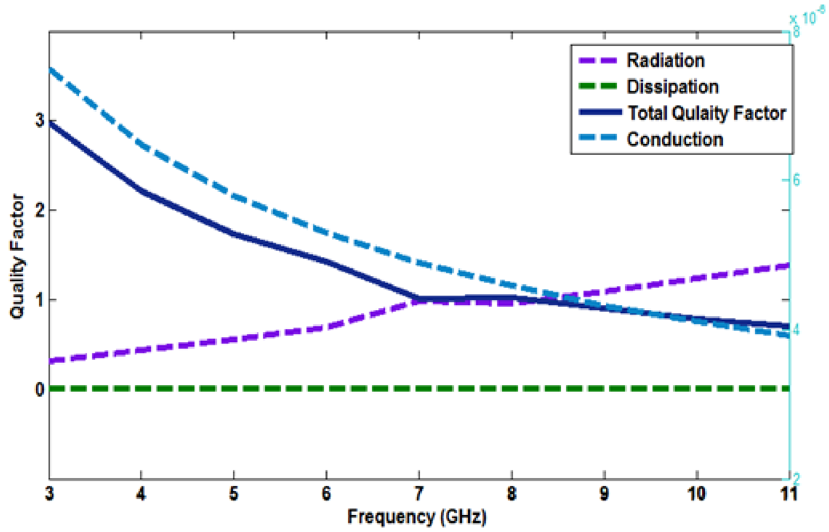

Figure 5.18: Quality Factor Plots of the Proposed Antenna

Since the quality factor due to dielectric loss (Q_d) is totally dependent of the loss tangent of the material, hence there is no variation of it over the entire frequency range. For FR4 epoxy material, the loss tangent is 0.02, hence the quality factor due to dielectric loss is 0.02. The value of quality factor associated with the conductor loss (Q_c) depends on the dimension of the antenna, resonant frequency and the electrical conductivity of the material used in the designing for the patch. The material used for the patch is copper having the conductivity of 5.85 x 10^{-5} units. The quality factor associated with this conduction loss is least and its value is very marginal due to the low value of the electrical conductivity of the copper.

The main factor account for the total quality factor is that of the radiation loss. Hence it is clear from the Figure 5.18 that the curve showing the total quality factor (Q_T) and that associated with the radiation loss (Q_r) are almost close to each other over the entire frequency range. There is marginal variation in the frequency below 3 GHz. patch dimension, the substrate property and the operating frequency are the parameter affecting the quality factor due to radiation.
At 6.5 GHz of resonant frequency of the design, the total quality factor obtained from the plot is 1.37. Putting this value in the equation 5.6, the theoretical bandwidth is determined. The theoretical bandwidth comes out to be 4.3 GHz.

5.5 Comparison between Theoretical and Measured Values of Impedance and Bandwidth

The theoretical impedance of the patch is calculated to be 39.63 Ω.

The measured value of the impedance is 32.39 Ω.

The theoretical bandwidth is calculated to be 4.3 GHz.

This measured bandwidth is found to be 4.5 GHz.

A close proximity of above mentioned two values gives a good validation of the result.

5.6 Chapter Summary

The objective of the work would not accomplish unless a proper validation is presented. The results achieved from the simulation and the measurements of the antenna are compared here. The comparisons of the results of the passive parameters are presented. The various parameters used in the comparison are the return loss, voltage standing wave ratio, and through power of the antenna. It also contains the active parameter characterization such as gain, directivity, and radiation efficiency and radiation pattern. Impedance calculation using transmission line method is also carried out with the result in the proximity of the measured value. The authentication of the work is also coagulating by the comparing the theoretical bandwidth and the measured bandwidth of the antenna.

Chapter 6

Conclusion and Future Scope

Research on microstrip antennas has no limit to enhance its performances. The utility of these antennas have completely changed the scenario of communication technology. The compactness of these antennas is also required in satellite links. The present work is proposed to design and development of a compact microstrip antenna. Various optimizations in the geometry of the rectangular planer antenna have been carried out to enhance the bandwidth to fulfil the requirement of ultra wide band.

In the present work, in order to design the specific ultra wide band antenna having simpler, planer and compact structure, the numerous planer resources for the broadening of the rectangular planer structure has been presented. The required bandwidth is accomplished with the optimization of width of the patch, height of the substrate, dimension of the slots, position of the slots, numbers of regular slots, dimension and number of regular notches along with the optimization of the dimension of the substrate and the ground plane. All the passive parameters accomplished by the test antennas are much more than the Ultra Wide Band specification.

The need of the hour in satellite communication going in ultra-wide band is planer and compact antenna. Researchers have achieved the anticipated antenna operating in the ultra-wide band frequency. Most of the antenna structures are not compact. Some of the researcher presented a complex structure. The test antenna 3 of this work, having rectangular in shape loaded with three regular rectangular slots and overall dimension of 29 mm by 26 mm, exhibits a bandwidth of 5.1 GHz, a return loss of -39 dB and gain 1.12 dB. The design of Samal et al [55] is rectangular in shape loaded with one circular and T-shape slot. The feeding is double structure microstrip line. Its overall dimension is 87 mm by 76 mm and exhibits a bandwidth of 5.8 GHz, a return loss of -38 dB and a gain of 6 dB. The design presented by Hu et al [60] is a double trapezoidal loaded with a T-shape slot having an overall dimension is 48 mm by 46 mm. It displays a bandwidth of 4.6 GHz, a return loss of -20 dB and a gain of 4 dB. The design presented by of Azim et al [77] is rectangular in shape loaded with an overall dimension of one 22 mm by 24 mm, but is tapered with tuning stubs on its back side. The bandwidth display by this antenna is 7 GHz with a return loss of -20 dB and the gain of the antenna is 5.4 dB. The design of Gautam et al [79] has a dimension of 25 mm by 26 mm, but it is a multifaceted structure having many slots of varying lengths. The feeding is done by coplanar wave guide. It exhibits a bandwidth of 7 GHz and a return loss of -20 dB.

Associating the basic parameters of the test antenna in the present work with that of the recent noticeable works of the researchers (as specified above) state that the test antenna is the simplest and compact in structure. The regular structure feed with microstrip line would be creating this design compatible with the integrated circuits and useful in satellite communication.

The Thesis work has been complete with the design and development of the specified Ultra Wide Band antenna. This developed antenna is a simpler, compact, low volume and rectangular in shape. It achieved a wide bandwidth of more than 5 GHz. The work provided an insight into the various method of enhancing the bandwidth of the microstrip antenna. It will provide a platform for the researchers in realizing the implementation of these geometries in wireless communication systems.

The concentration of the work is on the bandwidth enhancement. The other constraint of the antenna is its low gain. Therefore a vast scope exists for the development of microstrip antenna with higher gain. A more detail understanding of the impedance variation and other feeding techniques would lead to improvement. The use of popular mathematical optimization tools, such as genetic algorithm, particle swarm optimization, Bayesian algorithm, evolutionary algorithm would be helpful in performance of the microstrip antenna by a fine and detail optimization of its various parameters. Since the ultra wide band occupies most of the C band and X band of the super high frequency, hence a multi channel ultra wide band antenna would also afford a solution to many existing systems in these bands.

Compact and planer ultra wide band antenna is desirable for the shrinking communication devices. Future research may emphasis on the design by using new substrate, reduction in the size with more gain of these antennas. The quality of the communication link would require directional antenna with high gain. Therefore, research on the arrays of the ultra-wide band antenna or the directional antenna would be an interesting field.

Bibliography

[1] Crookes, W. (1892), Some Possibilities of Electricity, Fortnightly Review, pp. 174-176.

[2] Kraus, J.D. (1985), Antenna since Hertz and Marconi, IEEE Transaction on Antenna and Propagation, Vol. 33, No. 2, pp. 131-137.

[3] Fowler, C.A., Entzminger, J., and Corum, J. 1990), Assessment of Ultra Wide Band Technology, IEEE Aerospace and Electronic Systems Magazine, pp. 45-49.

[4] Schantz, S. (2005), The Art and Science of Ultra Wideband Antennas, Artech House.

[5] Balanis, C.A. (1992), Antenna Theory: A review, Proceeding of IEEE, Vol. 80, No. 1, pp. 7-23.

[6] Collin, R.E. (1985), Antenna and Radio-wave Propagation, McGraw Hill.

[7] Tai, C.T., and Pereira, C.S. (1976), An Approximate Formula for Calculating the Directivity of Antenna, IEEE Transaction on Antenna and Propagation, Vol. 24, No. 2, pp. 235-236.

[8] Deschamps, G. A.(1953), Microstrip Microwave Antennas, Third Symposium on the USAF Antenna Research and Development Program, University of Illinois, Monticello, Illinois, October 18-22.

[9] Munson, R. E. (1972), Microstrip Phased Array Antenna, 22nd Annual USAF Antenna Symposium.

[10] Munson, R. E. (1973), Single Slot Cavity Antennas Assembly, U.S. Patent No. 3713162.

[11] Munson, R. E. (1974), Conformal Microstrip Antennas and Microstrip Phased Arrays, IEEE Transactions on Antennas and Propagation, January 1974, Vol. 22, No. 1, pp. 74-78

[12] Howell, J. Q. (1975), Microstrip Antennas, IEEE Transactions on Antennas and Propagation, Vol. 23, pp. 90-93.

[13] Pozar, D. M., and Schaubert, D.H. (1995), Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays, IEEE Press, New York.

[14] Bahl, I. J., and Bhartia, P. (1980), Microstrip Antennas, Artech House.

[15] Carver, K. R. and Mink, J.W. (1981), Microstrip Antenna Technology, IEEE Transaction on Antennas and Propagation, Vol. 29, pp. 2-24.

[16] James, J. R., Hall, P. S., and Henderson, A. (1981), Some Recent Development in Microstrip Antenna Design, IEEE Transaction on Antennas and Propagation, Vol. 29, pp. 124-128.

[17] Mailloux, R. J., Mcllvenna, J.F. and Kernweis, N. P. (1981), Microstrip Array Technology, IEEE Transaction on Antennas and Propagation, Vol. 29, pp. 25-37.

[18] James, J. R., and Hall, P.S. (1989), Handbook of Microstrip Antennas, Vol. 1, Peter Peregrinus Ltd., London.

[19] Lee, H. F., and Chen, W. (1997), Advances in Microstrip and Printed Antennas, John Wiley & Sons, New York.

[20] Ammann M.J. and Chen, Z.N. (2003), Wideband Monopole Antennas for Multi-band Wireless Systems, IEEE Antennas and Propagation Magazine, Vol. 45, pp. 146-150.

[21] Guha, D., and AntarYahia, M. M. (2011), Microstrip and Printed Antennas: New Trends, Techniques and Applications, John Wiley & Sons, New York.

[22] James, J. R., Hall, P. S., Wood, C. and Henderson, A. (1981), Some Recent Development in Microstrip Antenna Design, IEEE Trans. Antenna and Propagation, Vol. 29, pp. 124-128.

[23] Huynh, T. and Lee, K. F. (1995), Single-Layer-Single-Patch Wideband Microstrip Antenna, Electronics Letters, Vol. 31, No. 16, pp. 1310-1312.

[24] Herscovici, N. (1998), A Wideband Single Layer Patch Antenna, IEEE Transaction on Antennas and Propagation, Vol. 46, pp. 471-473.

[25] Lo, Y. T., Solomon, D. and Richards, W. F. (1979), Theory and Experiment on Microstrip Antenna, IEEE Transactions on Antennas and Propagation, Vol. 30, No. 6, pp. 137-145.

[26] Menzel, W., and Grabherr, W. (1991), Microstrip Patch Antenna with Coplanar Feed Line, IEEE Microwave and Guided Wave Letters, Vol. 1, No. 11, pp. 340-342.

[27] Hall, P. S. (1987), Probe Compensation in Thick Microstrip Patches, Electronics Letters, Vol. 23, No. 11, pp. 606-607.

[28] Pozar, D. M. (1985), Microstrip Antenna Aperture-Coupled to a Microstrip Line, Electronics Letters, Vol. 21, No. 2, pp. 49-50.

[29] Pozar, M., and Targonski, S.D. (1991), Improved Coupling for Aperture-Coupled Microstrip Antennas, Electronics Letters, Vol. 27, No. 13, pp. 1129-1131.

[30] Pozar, D. M., and Kaufman, B. (1987), Increasing the Bandwidth of a Microstrip Antenna by Proximity Coupling, Electronics Letters, Vol. 23, No. 8, pp. 368-369.

[31] Roy, J. S., Shaw, S. K., Paul, P., Poddar, D. R., and Chowdhury, S. K. (1991), Some Experimental Investigations on Electromagnetically Coupled Microstrip Antennas on Two Layer Substrate, Microwave Optical Technical Letters, Vol. 4, No. 9, pp. 236-238.

[32] Smith, R. L., and Williams, J.T. (1992), Coplanar Waveguide Feed for Microstrip Patch Antenna,Electronics Letters, Vol. 28, No. 25, pp. 2272-2274.

[33] Pozar, D., and Kaufman, B. (1988), Comparison of Three Methods for the Measurement of Printed Antenna Efficiency, Antennas and Propagation, IEEE Transactions on Antenna and Propagation, Vol. 36, pp. 136-139.

[34] Carver, K.R., Coffey, E.L. (1979), Theoretical Investigation of the Microstrip Antennas, Technical Report, PT-00929, Physical Science Laboratory, New Mexico State University.

[35] Reineix, A., and Jecko, B. (1989), Analysis of Microstrip Patch Antennas using Finite Difference Time Domain Method, IEEE Transactions on Antennas and Propagation, Vol 37. No. 11, pp: 1361-1369.

[36] Garg, R., Bhartia, P., Bahl, I. J., and Ittipiboon, A. (2001), Microstrip Antenna Design Handbook, Artech House.

[37] Bhatacharya, A. K., and Garg, R. (1985), Generalized Transmission Line Model for Microstrip Patches, IEE Proceeding on Microwaves, Antennas Propagation, Vol. 132, No. 2, pp. 93-98.

[38] Gan, Y.B., Chua, C.P., and Li, L.W. (2004), An Enhanced Cavity Model for Microstrip Antennas, Microwave and Optical Technology Letters, Vol. 40, No. 6, pp. 520-523.

[39] Richards, W. F., Lo, Y. T., and Harrison, D. D. (1981), An Improved Theory of Microstrip Antennas with Applications, IEEE Transactions on Antennas and Propagation, Vol. 29, No. 61 pp. 38-46.

[40] Richard, W.F., Lo, Y.T., and Harrison. (1981), An Improved Theory for Microstrip Antennas and Applications, IEEE Transactions on Antennas and Propagation, Vol. 29, pp. 38-46.

[41] Newman, E. H., and Tulyathan, P. (1981), Analysis of Microstrip Antennas using Method of Moments, IEEE Transactions on Antennas Propagation, Vol. 29, pp. 47-53.

[42] Silvester, P. (1973), Finite Element Analysis of Planar Microwave Network, IEEE Transaction on Microwave Theory Technology, Vol. 21, pp. 104-108.

[43] Federal Communications Commission (2002), Revision of Part 15 of the Commission's Rules regarding Ultra Wide Band Transmission Systems, First Report and Order, ET Docket 98-153, FCC, Washington, DC.

[44] Schantz, H. (2004), A Brief History of UWB Antennas, IEEE Aerospace and Electronic Systems Magazine, Vol. 19, No. 4, pp. 22-26.

[45] Siwiak, K., and McKeown, D. (2004), Ultra Wideband Radio Technology, John Wiley & Sons, New York.

[46] Quintero, G., Zurcher, J.F., Skrivervik, A.K. (2010), Ultra Wideband, Short-Pulse Electromagnetics, Springer, Ch. 29, pp. 269-278.

[47] Roberto Aiello, G., Rogerson, G.D. (2003), Ultra Wideband Wireless Systems, IEEE Microwave Magazine, pp. 36-47.

[48] Allen, B., Dohler, M., Okon, E.E., Malik, W.Q., Brown, A.K., and Edwards, D.J. (2007), Ultra Wideband Antennas and Propagation for Communication, Radar and Imaging, John Wiley & Sons, New York.

[49] Clarke, A.C. (1945), Extraterrestrial Relays, Wireless World, Vol. 51, No. 10, pp. 305-308.

[50] Charyk, J.V. (1977), Communication satellites, Von Karman Lectureship in Astronautics, 13th AIAA Annual Meeting, Washington, D.C., pp. 77-323.

[51] Pritchard, W.L. (1977), Satellite Communications - An Overview of the Problems and Programs, Proceeding of IEEE, Vol. 65, No. 3, pp. 294-307.

[52] Ha, Tri T. (1990), Digital Satellite Communications, McGraw Hill.

[53] Deng, C., and Xie, Y. J. (2010), Dual Band-Notched Design of Rectangular Monopole Antenna For UWB Applications, Progress in Electromagnetics Research C, Vol. 14, pp 213-225.

[54] Zhou, D., Gao1, S., Zhu, F., Abd-Alhameed, R. A., and and Xu, J. D. (2012), A Simple and Compact Planar Ultra Wide-Band Antenna With Single or Dual Band Notched Characteristics, Progress in Electromagnetics Research, Vol. 123, pp 47-65.

[55] Samal, Purna B., Soh, Ping Jack., and Vandenbosch, Guy A. E. (2013), A Systematic Design Procedure for Microstrip-Based Unidirectional UWB Antennas, Progress in Electromagnetics Research, Vol. 143, pp 105-130.

[56] Sadat, S., Fardis, M., Geran, F., and Dadashzadeh, G. (2007), A Compact Microstrip Square-Ring Slot Antenna for UWB Applications, Progress in Electromagnetics Research, Vol 67, pp 173-179.

[57] Sadat, S., Houshmand, M., and Roshandel, M. (2007), Design of a Microstrip Square-Ring Slot Antenna Filled by an H-Shape Slot for UWB Applications, Progress in Electromagnetics Research, PIER 70, pp 191-198.

[58] Zivkovic, I., and Scheffler, K. (2013), A New Innovative Antenna Concept for Both Narrow Band and UWB Applications, Progress in Electromagnetics Research, Vol. 139, pp 121-131.

[59] Zhang, G.M. , Hong, J.S., and Wang, B.Z. (2008), Two Novel Band-Notched UWB Slot Antennas fed by Microstrip Line, Progress in Electromagnetics Research, PIER 78, pp 209-218.

[60] Hu, Y.S., Li, M., Gao, G. P., Zhang, J. S., and Yang, M. K. (2010), A Double-Printed Trapezoidal Patch Dipole Antenna for UWB Applications with Band-Notched Characteristic, Progress in Electromagnetics Research, PIER 103, pp 259-269.

[61] Azim, R., and Islam, M. T. (2013), Compact Planar UWB Antenna with Band Notch Characteristics for WLAN and DSRC, Progress in Electromagnetics Research, Vol. 133, pp 391-406.

[62] Lech, R., Marynowski, W., and Kusiek, A. (2013), Finite Ground CPW-fed UWB Antenna over the Metallic Cylindrical Surfaces, Progress in Electromagnetics Research, Vol. 140, pp 545-562.

[63] Esfahlani, S. H. S., Tavakoli, A., and Dehkhoda, P. (2011), A Compact Single-Layer Dual-Band Microstrip Antenna for Satellite Applications, IEEE Antennas and Wireless Propagation Letters, Vol. 10, pp. 931-934.

[64] Ghassemi, N., Rashed-Mohassel, J., and Neshati, M. H. (2008), Microstrip Antenna Design for Ultra Wideband Application by using Two Slots, Progress in Electromagnetics Research Symposium, Hangzhou, China, pp 159-161.

[65] Chatterjee, S., Choudhury, S.K., Sarkar, P. P., and Sarkar, D. C. (2014), Bevel Microstrip Printed Antenna for Satellite Communication, Indian Journal of Pure and Applied Physics, Vol. 52, pp 760-766.

[66] Islam, M. T., Shakib, M. N., and Misran, N. (2009), Multi-Slotted Microstrip Patch Antenna for Wireless Communication, Progress in Electromagnetics Research Letters, Vol. 10, pp 11-18.

[67] Kasi, B., Ping, L. C., and Chakrabarty, C. K. (2011), A Compact Microstrip Antenna for Ultra-Wideband Applications, European Journal of Scientific Research, Vol.67 no.1, pp. 45-51.

[68] Lim, K. S., Nagalingam, M., and Tan, C. P. (2008), Design and Construction of Microstrip UWB Antenna with Time Domain Analysis, Progress in Electromagnetics Research M, Vol. 3, pp 153-164.

[69] Chen, Z. N., Terence S. P. See., and Qing, X. (2007), Small Printed Ultra-Wide Band Antenna With Reduced Ground Plane Effect, IEEE Transactions on Antennas and Propagation, Vol. 55, no. 2, pp 383-388.

[70] Soliman, Ezzeldin A., Raedt, Walter De., and Vandenbosch, Guy A. E. (2008), Microstrip-Fed Cusp Antenna for Ultra-Wide Band Communication Systems, International Journal of RF and Microwave Computer-Aided Engineering, Wiley Periodicals, pp 23-28.

[71] Shinde, P.N., and Mishra, B. K. (2013), On the Design of Compact UWB Antenna with 7.5 GHz Band Notch Characteristics, IEEE International Conference on Advances in Technology and Engineering (ICATE), pp 1-4.

[72] Adan, S., Abd-Alhameed, R. A., Hraga, H. I., Zainal Abidan, Z., Usman, M., and Jones, S. M. R. (2009), Design Studies of Ultra-Wideband Microstrip Antenna for Ultra-Wideband Communication, IEEE Antennas & Propagation Conference November 2009, Loughborough, UK, pp 365-368.

[73] Rahayu, Y., Ngah, R., and Rahman, T. A. (2010), Various Slotted UWB Antenna Design, IEEE Sixth International Conference on Wireless and Mobile Communications, pp 107-110.

[74] Tammam, E., Yang, L., Allam, A., Ragab, Mohammed., Yoshitomi, K., Pokharel, R., and Yoshida, K. (2012), Design of a Small Size

UWB Antenna with Band-rejection Characteristics, IEEE Japan-Egypt Conference on Electronics, Communications and Computers (JEC-ECC), pp 112-117.

[75] Norzaniza, A. T., and Matin, M. A. (2013), Design of Microstrip UWB Antenna with Band Notch Characteristics, IEEE TENCON Spring Conference, pp 51-52.

[76] Wiesbeck, W., Adamiuk, G., and Sturm, C. (2009), Basic Properties and Design Principles of UWB Antennas, Proceedings of the IEEE, Vol. 97,No. 2, pp 372-385.

[77] Azim, R., Islam, Mohammad T., and Misran, N. (2011), Compact Tapered-Shape Slot Antenna for UWB Applications, IEEE Antennas and Wireless Propagation Letters, Vol.10, pp. 1190-1193.

[78] Elkorany, A.S., Elhalafawy, S.M., Shahid, S., and Gentili, G.G. (2015), UWB Integrated Microstrip Patch Antenna with Unsymmetrical Opposite Slots, in IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 2015 pp. 426-429.

[79] Gautam, A.K., Yadav, S., and Kanaujia, B.K. (2013), A CPW-Fed Compact UWB Microstrip Antenna, IEEE Antennas and Wireless Propagation Letters, IEEE, Vol. 12, pp. 151-154.

[80] Hassanien, M.A., Hamad, E.K.I. (2010), Compact Rectangular U-shaped Slot Microstrip Patch Antenna for UWB Applications, IEEE Middle East Conference on Antennas and Propagation (MECAP), pp. 1-4.

[81] Wu, Qi., Jin, R., and Geng, J. (2010), A Single-Layer Ultra-wide band Microstrip Antenna, IEEE Transaction on Antennas and Propagation, Vol. 58, no.1, pp. 211-214.

[82] Bahl, I.J., and Bhartia, P. (1980), Microstrip Antennas, Artech House, USA.

[83] Shackelford, A. K., Lee Kai- Fong and Luk, K. M. (2003), Design of Small-Size Wide-Bandwidth Microstrip-Patch Antennas, IEEE Antennas and Propagation Magazine, Vol. 45, No. 1, pp. 75-83.

[84] Balanis, C.A. (2005), Antenna Theory - Analysis and Design, John Wiley and Sons.

[85] Jackson, D.R., and Alexopoulos, N.G. (1991), Simple Approximate Formulas for Input Resistance, Bandwidth and Efficiency of a Resonant Rectangular Patch, IEEE Transaction on Antenna and Propagation, Vol. 39, pp. 407-410.

[86] Kumar, G., and Ray, K. P. (2003), Broadband Microstrip Antenna, Artech House.

[87] Pozar, D. M. (1995), A Review of Bandwidth Enhancement Techniques for Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays, IEEE Press, New York, pp. 157-166.

[88] Raja Abdullah, Yoharaaj, R.S.A.R.D., and Ismail, A. (2006), Bandwidth Enhancement Technique in Microstrip Antenna for Wireless Applications, Progress in Electromagnetic Research, Vol. 2, No.6, pp. 633-639.

[89] Luk, K. M., Mak, C. L., Chow, Y. L. and Lee, K. F. (1998), Broadband Microstrip Patch Antenna, Electronics Letters, Vol. 34, No. 15, pp. 1442-1443.

[90] Wong, K.L. (2002), Compact and Broadband Microstrip Antennas, John Wiley & Sons.

[91] Pozar, D.M. (2005), Microwave Engineering, John Wiley & Sons.

[92] Sze, J. Y., and Wong, K.L. (2001), Bandwidth Enhancement of a Microstrip Line Fed Printed Wide Slot Antenna, IEEE Transactions on Antennas and Propagation, Vol.49, No.7, pp. 1020-1024.

[93] Maddani, G. P., Sameena, N.M., and Mulgi, S.N. (2010), Wide Bandwidth, High- Gain Slot-loaded Rectangular Microstrip Antennas, Microwave and Optical Technology Letters, Vol. 52, No. 12, pp. 2841-2845.

[94] Gupta, K.C., Garg, R., Bahl, I., and Bhartia, P. (1996), Microstrip Lines and Slotlines, Artech House.

[95] Bhattacharyya, A.K. (1991), Effects of Ground Plane Truncation on the Impedance of a Patch Antenna, IEE Proceeding, Vol. 138. No. 6, pp. 560-564.

[96] Rida, A., Yang, L., and Tentzeris, M.M. (2007), Design and Characterization of Novel Paper-based Inkjet-printed UHF Antennas for RFID and Sensing Applications, Proceedings of the IEEE Antennas and Propagation Society International Symposium, pp. 2749-2752.

[97] Agafonov, K.V., Balyaev, B.A., and Leksikov, A.A. (2006), Automated Coordinatograph for Manufacture of Microstrip Circuits, 16th International Conference on Microwave and Telecommunication Technology, pp. 637-638.

[98] Verspecht, J. (2005), Large Signal Network Analysis, IEEE Microwave Magazine, Vol. 6, No. 4, pp. 82-92.

[99] Pues, H., and Van de Capelle, A. (1984), Accurate Transmission Line Model for the Rectangular Microstrip Antenna, IEE Proceedings, Vol. 131, No. 6, pp. 334-340.

[100] Sengupta, D.L. (1983), The Transmission Line model for Rectangular Patch Antenna, IEEE Symposium Digest, Antenna and Propagation, Vol. 1, pp. 158-161.

[101] Gopinath, A. (1981), Maximum Q-factor of Microstrip Resonators, IEEE Transactions on Microwave Theory and Techniques, Vol. 29, No. 2, pp. 128-131.

List of Publications

1. R. Mishra, P. Kuchhal, A. Kumar (2015), **Impact of Slots on the Performance Analysis of Microstrip Antenna**, *International Journal of Applied Engineering Research*, vol 10, no. 16, pp. 36313-17. [**Scopus Indexed**]

2. R. Mishra, P. Kuchhal, A. Kumar (2015), **Effect of Height of the Substrate & Width of the Patch on the Performance Characteristics of Microstrip Antenna**, *International Journal of Electrical and Computer Engineering*, vol 5, no. 6, pp. 1441-45. [**Scopus Indexed**]

3. R. Mishra, P. Kuchhal, A. Kumar (In press), **Antenna Path Loss Propagation at 1800 MHz in L-Band**, *Springer Proceedings* [**Scopus Indexed**].

4. R. Mishra, Divyanshi Sinha, Anushka Swarup, P. Kuchhal (2015), **Design & Simulation of a High Gain Patch Antenna Array at X-Band**, *14th IEEE & URSI International Conference on Microwave Antenna & Remote Sensing*, Jodhpur.

5. R. Mishra, P. Kuchhal, Sakshi Drall (accepted for publication in Feb 2016), **Bandwidth Enhancement of a Microstrip Patch Antenna using Suitable Feed Line Dimension**, *9th Annual Antenna Measurement & Testing Society International Conference*, Panaji.

6. R. Mishra, R. K. Chaurasia (2015), **Performance Analysis of PSK on Radio Channels**, *Volume 16: Edition on Advances in Engineer-*

ing & Management Research of HCTL Open International Journal of Technology Innovations and Research (IJTIR), July 2015.

7. R. Mishra, R. K. Chaurasia (2013), **Analytical Calculation of a Radio Propagation Model in the Implementation of Cellular Mobile System of Valley of Dehradun City**, *HCTL Open International Journal of Technology Innovations and Research (IJTIR)*, Volume 4, July 2013.

CURRICULUM VITAE

RANJAN MISHRA

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Experience:

A total of**16 years** of experience

- Working as an Assistant Professor (Selection Grade) in College of Engineering Studies at University of Petroleum & Energy Studies, Dehradun since June 2011.

- Workedas aSenior Faculty member at ICFAI institute of Science & Technology, ICFAI University, Dehradun from August 2008 to June 2011.

- Worked as an Assistant Professor in Mody Institute of Technology and Science, a Deemed University, Lakshmangarh, Rajasthan from September 2004 to August 2008.

- Worked as a Faculty in National Institute of Science and Technology, Berhampur, a Premiere Engineering Institute from July 2000 to September 2004.

- Research experience of 6 months at International Centre for Radio Science, Jodhpur from November 1999 to June 2000

Qualifications:

- **M.Tech** in **Electronics and Communication Engineering** (**Microwaves)** from The University of Burdwan, WB, and obtained a **CGPA of 8.6** in year 1999.

Current Academic and Administrative Responsibilities:

- Teaching courses at B.Tech and M.Tech level in the field of Communication Engineering domain.
- Program Head of Electronics Department
- Placement and Internship Coordinator

Academic Achievements:

Delivered an invited talk on ‘Design of Microstrip Antenna’ at International conference ICMEMR in Dehradun on July, 2015

Delivered **two invited lectures** on 'Optical Fibers & Cables' and 'Optical Fiber Measurements' at **Short Term Training Programme** on Modern Trends in Opto Electronics conducted by Indian Society for Technical Education (**ISTE**) at UCP Engineering School, 11 - 22 Nov. 2002, Berhampur, Orissa

Secretary of 1st national conference conducted by ICRS on the occasion of 100 years of the discovery of Radio waves by Sir J.C. Bose in Jodhpur in the year 1998.

Book Published:

- **R. Mishra,** V. Mittal & RK Chaurasis, Interference and Path loss of Cellular Technology, Lambert Publication, 2013

Journal Paper Published:

- ***R. Mishra**, R.K. Chaurasia, Performance Analysis of PSK on Radio Channels,* Volume 16: Edition on Advances in Engineering & Management Research of HCTL Open International Journal of Technology Innovations and Research (IJTIR), July 2015.
- **R. Mishra**& RK Chaurasia, Analytical calculation of a radio propagation model in the implementation of cellular mobile system of valley of Dehradun city, , HCTL Open International Journal of Technology Innovations and Research (IJTIR), Volume 4, July 2013.
- **R. Mishra,** V. Mittal, A. Atrey, Analysis of Co-Channel Interference under various Radio Propagation Environments, TJPRC, May 2012.
- O.P.N. Calla, M.C. Borah, P. Vashishtha, **R. Mishra**, A. Bhattacharyaya and S.P. Purohit, *Study of the Properties of Dry and Wet Loamy sand Soil at Microwave frequencies*, Indian Journal of Radio and Space Physics, Vol 28, June 1999, pp 109-111. New Delhi.
- RK Chaurasia, R Mishra. A Rathore& H Kumar, “Road Map and Challenges in 4G Wireless System”, IET Communications, UK
- RK Chaurasia, R Mishra & R Ansari, “Handoff techniques in cellular mobile communication”, Journal of Computer Science and Mathematics.

.

Conference Papers Published:

- RK Chaurasia, **R Mishra**, Performance Analysis of IEEE 802.11b using different modulation scheme an dcoding techniques, International conference, IAET 2014, Jaipur, October 2014.
- **R. Mishra**, R.K. Chaurasia, P. Sharma, D. Jaipuria, and P. Singh, *Analysis of a Radio Propagation Model in the Planning of Cellular System of Jaipur City.*Proc. of 4th International Conference on Radio Science, souvenier pp 30, Feb 27-29, 2008, Jodhpur. India
- R. K. Chaurasia, **R. Mishra,** Kothari, N., Bariyawal, M., and Ansari, R.,*Comparative Analysis of Co-Channel Interference under Various Radio Propagation Enviornment*, Proc. of 4th International Conference on Radio Science, souvenier pp 36, Feb 27-29, 2008, Jodhpur. India
- **R. Mishra** and RK Chaurasia, *System Architecture and Technologies status of W-ATM in personal communication networks,* Proc. of International Conference on Current Trends in Information Technology, SRKR Engineering College, pp 225-227, Oct 1-3, 2005, Bhimavaram, A.P.
- J. Mohanty, **R. Mishra** and A. K. Patnaik, *Making Global Knowledge Resources Accessible to Remote Areas through Telecommunication Technology*, Presented in Seminar on Technology for the IndianVillage, 6th Annual Convention of ISTE Orissa

Section, National Institute of Science & Technology, 4th April, 2003, Berhampur, Orissa, India.

- **R. Mishra** and J. Mohanty, *Dynamic Bandwidth Management for Optimum Data Transmission using Optical Fiber Technology,* Proc. of National Conference on Control, Communication and Information System CCIS - 2004, Goa College of Engineering, pp. 10-13, Jan. 23-24, 2004, Ponda, Goa, India.
- **R. Mishra** and O.P.N. Calla, *Sensing Electrical Parameters of Water through Microwave Frequencies*, 1st International Conference on Microwaves, Antenna, Propagation & Remote Sensing, Dec. 15-19, 2003, Jodhpur. India.
- A. K. Singh, **R. Mishra** and A. Mohan, *Sysnthesis and Fault Detection of Combinational Networks using Arithmetic Spectrum*, Proc. of International Conference on Information Technology, CIT-2001, pp. 347-350, Dec. 20-22, 2001, National Institute of Science and Technology, Berhampur, India.
- A.K. Singh, **R. Mishra** and A. Mohan, *A New Arithmetic Spectrum for Synthesis and Testing of Combinational Circuit*, Proc. of VLSI 2001, pp. 95-98., Sep. 29-30, 2001, Indian Institute of Technology, Roorkee. India.
- A.K. Singh, **R. Mishra** and A. Mohan*, A New Arithmetic Spectrum for Fault Detection in Digital Circuit*, Proc. of International Conference on OTAET - 2001, pp. 36-37, Sep. 22-23, 2001, Raja Balwant Singh College, Agra. India.
- O. P. N. Calla and **R. Mishra** , *Choice of Frequency for Measuring the Salinity of Water*, Proc. of National conference of Study of Land using Radio Techniques, Jan. 18-19 2000, Jodhpur. India .
- **R. Mishra** and O. P. N. Calla, *Analysing the Variation of Electrical Parameter of Water at Microwave Frequencies*, Asia Pacific Microwave Conference, APMC 2004, University of Delhi South Campus, Dec. 15 - 18, New Delhi, India.

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I hereby declared that the above information is true to the best of my knowledge.