DESIGN AND IMPLEMENTATION OF PLANAR WIDE BAND ANTENNA FOR WIRELESS COMMUNICATION APPLICATIONS

Thesis Submitted For the Award of the Degree of

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in

Electronics and Communication Engineering

By

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DECLRATION

I hereby declare that this research work "Design and Implementation of planar wide band antenna for wireless communication applications" has been composed solely by myself and has not been submitted anywhere. It was carried out by me for the degree of Doctor of Philosophy in Electronics & Communication Engineering under the guidance and supervision of Prof. Dr. Praveen Kumar Malik, Lovely Professional University, Phagwara Punjab, India.

The interpretations put forth are based on my reading and understanding of the original texts and they are not published anywhere in the form of books, monographs or articles. The other books, articles and websites, which I have made use of are acknowledged at the respective place in the text.

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- The work contained in this thesis is original and has been done by me under the guidance of my supervisor (s).
- The work has not been submitted to any other Institute for the award of any other degree or diploma.
- I have followed the guidelines provided by the Institute in preparing the thesis.
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Praveen Tiwari

41800804

Date: 10 Dec 2022

CERTIFICATE

This is to certify that the thesis entitled **“Design and Implementation of planar wide band antenna for wireless communication applications”** being submitted by Praveen Tiwari for the degree of Doctor of Philosophy in Electronics & Communication Engineering from Lovely Professional University, Jalandhar is a record of bonafide research work carried out by her under my supervision at the School of Electrical and Electronics Engineering. In our opinion, this is an authentic piece of work for submission for the degree of Doctor of Philosophy. To the best of our knowledge, the work has not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

With the rapid expansion of wireless communication applications, new design specifications for integrated devices have emerged, requiring more compactness, low profile, and low cost. Antennas play an important role in wireless signal transmission by converting electrical impulses into electromagnetic waves and acting as a transducer on both the transmitter and receiver sides. Antenna miniaturisation is becoming increasingly important to achieve optimised design for handheld wireless communication gadgets, and to do so, PCB technology based microstrip patch antennas have become a buzz word that is attracting research attention for their smaller size, good gain, and bandwidth characteristics. Furthermore, wireless devices such as mobile phones use a variety of technologies such as the ISM band for Wi-Fi, Bluetooth, BLE and Wi-MAX, GSM, CDMA, and so on. Traditional antennas only work on a single frequency band, but there is now a need to design multiple band antennas that can resonate on various frequency bands and eliminate the need for multiple antennas in one device. Antennas must meet the FCC's minimum band criteria for each wireless standard in order to achieve high data transmission rates.

Therefore, microstrip patch antenna is highly regarded to be the best candidate for wireless communication applications due to several characteristics that meet the requirements of wireless communication devices like light weight, low profile, easy integration to microwave devices and minimal cost due to fabrication by using PCB technology. But it does have some drawbacks such as lower gain and bandwidth. Numerous strategies for microstrip patch antenna gain, bandwidth augmentation with increased compactness, and wideband features have been proposed in the literature. Multiple band characteristics can be achieved in a microstrip patch antenna by modifying the patch structure, which serves as the principal radiator, primarily employing two ways. To accomplish multiband behaviour, the first technique is to build multiple patches for different frequencies, or the second option is to rise the electrical length in patch without

rising overall antenna dimensions. The second method is most commonly utilized and it involves the use of fractal and defective ground structures.

The usage of fractal structures in antenna design has had a big impact on how they're used in different communication technologies. The fractal shapes are well known for its property of area occupancy and self-symmetry. Antenna reduction can be performed by electrically expanding the length of current transmission in the patch that acts as the principal radiator without physically modifying the antenna structure because of these features. The self-similarity property states that the same geometry is repeated several times but with smaller dimensions than the preceding one, resulting in multiple resonance and multiband behaviour. Furthermore, due to its simple design, ground structures are employed to increase microstrip patch antenna modest gain, narrow impedance bandwidth, and suppress cross-polarization defects.

The main aim of the thesis is to design patch antenna having wide bandwidth frequencies for wireless applications. Planar antenna is designed which is having Gain more than 10dB. Small size antenna is designed which is suitable for the application of Wi-Fi and Wi-max which can operate in the range of higher frequencies (More than 10GHz). Proper design parameters and matching of the impedance is done to acquire the efficiency of the antenna more than 80% and radiation pattern is more directional. Impedance bandwidth is also kept in accord with the desired value of the antenna. Antenna performance is analyzed in terms of return loss, gain, and impedance bandwidth, VSWR and radiation pattern.

RESEARCH OBJECTIVES

During the state of the art of the research work presentation, following were the research objectives which were approved by the committee members:

a) Planar antenna will be designed which is having Gain more than 10dB.

b) Small size antenna will be designed which is suitable for the application of Wi-Fi and Wi-max which can operate in the range of higher frequencies (More than 10GHz).

c) Proper design parameters and matching of the impedance will be done to acquire the efficiency of the antenna more than 80% and radiation pattern is more directional.

d) Impedance bandwidth will also be kept in accord with the desired value of the antenna.

RESEARCH GAP

Based on the literature survey following research gaps are identified for planar MSA antenna: -

1. Gain of the different planar antenna is up to 10dB. Could be increase up to 12-15dB
2. Design of planar antenna for the use of Wi-Fi and Wi-Max with small size is required.
3. Design of MSA for the use of higher frequencies in term of 10~15 GHz is required.
4. Efficiency of the MSA antenna is up to 80% and Radiation pattern of the antenna is not directional.

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I would like to take this opportunity to extent my heartfelt thanks to all the faculty members of the departments who taught me during the course work session. My Ph.D. would not have started without the efforts put on by the course work faculties whose immense knowledge made it extremely easy for me to understand those subjects and pass my course work.

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ACRONYMS AND ABBREVIATIONS

Acronyms	Description
AF	Audio Frequency
AMC	Artificial Magnetic Conductor
AMPS	Advanced Mobile Phone Service
AR	Axial Ratio
ARBW	Axial Ratio Bandwidth
AUT	Antenna Under Test
BPF	Band Pass Filter
CDMA	Code Division Multiple Access
CPW	Coplanar Waveguide
CRO	Cathode-Ray Oscilloscope
CRT	Cathode-Ray Tube
CST	Computer Simulation Technology
DGS	Defected Ground Structures
DSL	Digital Subscriber Lines
DUT	Device Under Test
EBG	Electromagnetic Bandgap
EDR	Enhanced Data Rate
EIRP	Equivalent Isotopically Radiated Power
ETSI	European Telecommunications Standards Institute
FDGS	Fractal Defected Ground Structure
FHSS	Frequency Hopping Spread Spectrum
FR4	Flame Retardant 4
FSA	Fibonacci spiral antenna
FSPL	Free Space Path loss
GNSS	Global Navigation Satellite System
GBR	Gerber files

GPA	Ground plane aperture
HIPERMAN	High Performance Radio Metropolitan Area Network
HORYU-IV	High Voltage Technology Demonstration Satellite-4
IFS	Iterated Function System
LEO	Low Earth Orbit
LHCP	Left Hand Circular Polarized
LPWAN	Low-Power Wide-Area Network
LSNA	Linear Sensor Node Array
LTE	Long-Term Evolution
MM	Meta-material
MMOG	Multi Media Online Gaming
MPA	Microstrip Patch Antenna
MS	Meta Surface
MTA	Microwave Transition Analyzer
PCB	Printed Circuit Board
PHY	Physical Layer
PMPA	Planar Microstrip Patch Antenna
RFID	Radio-Frequency Identification
RL	Return Loss
RSL	Received Signal Level
SDT	Spectral Domain Technique
SMA	Sub-Miniature version A
SNA	Sliced Notch Antenna
TCDA	Tightly Coupled Dipole Array
TL	Total Loss
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave ratio
UMTS	Universal Mobile Telecommunications System

UHF	Ultra-High Frequency
UWB	Ultra Wide Band
WCS	Wireless Communication Services
Wi Fi	Wireless Fidelity
Wi Max	Worldwide Interoperability for Microwave Access

LIST OF SYMBOLS

Symbol	Description
H	Efficiency
Γ	reflection coefficient
ε_r	relative permittivity
tan δ	*loss tangent*
λ	Wavelength
c	speed of light
f_r	resonating frequency
Z_0	Characteristics Impedance
λ_g	Guided Wave Length

CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION

In consideration of exponential rise of wireless communications technologies and Internet services in previous years, the requirement of high data rate services has increased. As a result, the number of users increased dramatically, and it is clear that massive traffic congestion will be experienced in future communication networks. Good infrastructure is a major problem for manufacturers and service providers to supply additional capacity in networks in order to deliver efficient communication services. Another significant difficulty is the device's compactness. Wireless communication services encounter major issues such as multipath fading, co-channel interference, and delay spread, all of which reduce signal quality [1]. Researchers are experimenting with a variety of approaches to improve the efficiency of communication networks.

Wireless communication, as illustrated in Figure 1.1, is the most dynamic and quickest growing technology in the communication industry, wherein data can be transported from source to destination without the use of primary connections. Intriguingly, in any communication system, the transmitter and receiver play a crucial part in transferring information, and they can be positioned anywhere from a few metres to thousands of kilometres, as in Tele Vision remotes control a well as satellite communication [2]. Because not any directed means are utilised, signals are transmitted and received using antennas.

On the transmitter side, an antenna translates electrical signals into radio waves, and on the receiving side, it converts radio waves into electrical signals. It's also one of the most important components in achieving compactness in circuit design. Antennas of many kinds, such as the Horn, dipole, Planar Inverted-F Antennas, and patch antenna are available on the market [3]. Low-profile antennas are now preferred in communication systems to obtain great performance over a wide frequency range.

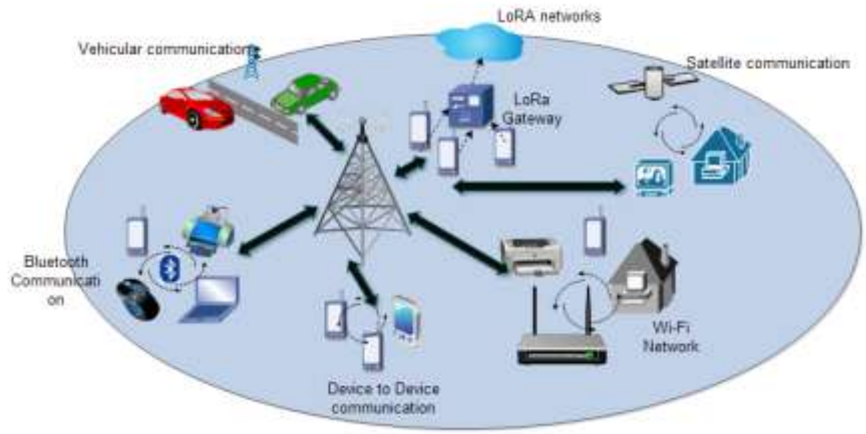

Figure 1.1 Wireless communication networks

Decamps first proposed microstrip patch antennas in 1953, but they have yet to become a reality. Munson and Howell were the first to put antennas into practise in the 1970s, many thanks for introduction of the PCB along with the widespread availability of dielectric substrate materials. MPA has gotten a lot of attention since then because of their multiple benefits, including lightweight, ease of manufacture utilising PCB technology, low cost, small size, and easy integration with microwave circuits [4-5].

Microstrip patch antennas have patch, which radiates, on one side of the dielectric substrate that acts as an resonating cavity and the ground plan at opposite edge [6]. As shown in Figure 1.2, antenna patch, which radiate scan have triangular, circular, square, rectangular, ring, or other shapes.

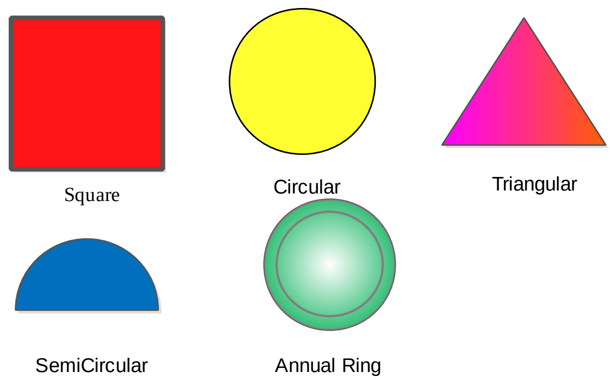

Figure 1. 2 Different patch structures used for Microstrip patch antenna

1.1.1 Types of Network Analyzer

a) Scalar Network Analyzer (SNA):

This type of network analyzer is used to determine the device's scalar amplitude properties (DUT). This is the most basic type of network analyzer.

b) Vector Network Analyzer (VNA):

It is primarily used to measure more parameters on the device under test than a scalar network analyzer. It is used to determine the amplitude and phase response of a signal.
The Large Signal Network Analyzer (LSNA) is primarily used to analyse radio frequency (RF) networks. It is used to determine the network's harmonic components and non-linearities. Additionally, it is referred to as a Microwave Transition Analyzer (MTA). VNAs are primarily used to determine the scattering parameters of passive components such as transmission cables, filters, couplers, antennas, and transfers. Additionally, the VNA is used to characterise active devices such as transistors and amplifiers using S-parameters. VNAs can be used to detect cable faults, to visualise breast tumours in the field of electromagnetic imaging, and so on.

1.1.2 Types of Spectrum Analyzer:

Spectrum analyzer can be of following types:

a) Filter Bank Spectrum Analyzer

Bank of filters Spectrum Analyzers are sometimes referred to as real-time spectrum analyzers. These are used to analyse audio signals and display variations in all input frequencies.

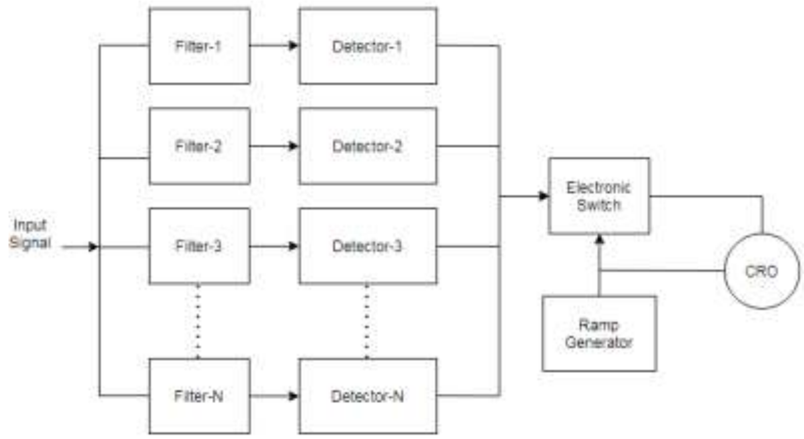

Figure 1.3 Block diagram of Filter Bank Spectrum Analyzer

It is composed of a series of band pass filters (BPF), each of which is tuned to allow for a specific set of frequencies. Each filter's output is routed to the detector circuit that follows it. The outputs from all detectors are connected via an electronic switch to the vertical plate of a Cathode Ray Oscilloscope (CRO), which sequentially passes the outputs to the CRO vertical plate and displays the frequency spectrum of the AF signal on the CRT screen.

b) Spectrum analyzer for super heterodyne

The first analyzer to be used was a super heterodyne analyzer, also known as a sweep analyzer. It is used to analyse the RF frequency range; if the signal amplitude is very large, it attenuates the signal using an input attenuator. It allows only those frequency components of the signal that are below the cut-off frequency to pass through. The spectrum analyzer operates on the same principle as various radio receivers: super-heterodyne. For frequency translation, it makes use of a mixer and a local oscillator. Due to the super-heterodyne principle, this type of spectrum analyzer has extremely large scan spans, up to several GHz. Additionally, this spectrum analyzer is capable of operating at extremely high frequencies. Figure 4.5 illustrates its block diagram.

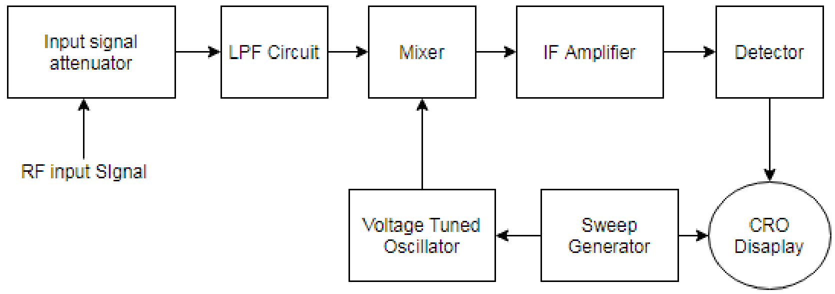

Figure 1.4 Block diagram of super heterodyne spectrum analyzer

The required Radio Frequency signal is applied through the input attenuator and attenuated if the signal amplitude is too large. Low pass filter (LPF) admits only signals with a frequency less than the cut-off frequency. The mixer circuit takes the input from the Low Pass filter and voltage tuned oscillator and generates difference frequency signals. The output of the mixer is further amplified by an Intermediate Frequency (IF) amplifier before being applied to the detector circuit, which controls the vertical plate deflection of the CRT tube, allowing the CRO to display the frequency spectrum of the RF signal on the CRT display.

A spectrum analyzer can be selected based on the signal range. Parameters that a spectrum analyzer can measure:

- Return loss
- Satellite antenna alignment
- Measurement of spurious signals
- Measurement of harmonics

1.2. WIRELESS STANDARDS

1.2.1 GSM

The European Telecommunications Standards Institute (ETSI) established a Global System for Mobile Communication (GSM), which is a digital mobile phone standard (European Telecommunications Standards Institute). It was first used in Finland in 1991. After that, it became a global standard for mobile phone communication by the mid-2010s, with more than 90% market share and acceptance by 193 countries. There are two types of GSM networks: 2G and UMTS (3G). 2G networks use the 900MHz or 1800MHz frequency bands, while 3G networks use the 2100 MHz frequency band [7-8]. The TDMA (Time division Multiple Access) principle is used in GSM. Different time slots are assigned to different uses, allowing for 8 full rate and 16 half rate channels/radio frequency at a data rate of 270.833Kbits/sec and a frame duration of 4.615ms. GSM handsets have a maximum power of 2 watts for GSM850/900 and 1 watt for GSM 1800/1900.

1.2.2 IEEE standard for WLAN

WLAN stands for wireless local area network, and it is mostly used to communicate using radio waves between computing devices such as laptops [9]. To accomplish high data rates, 802.11g was developed, which runs on the 2.4GHz ISM band and has a transfer rate of up to 54Mbps. Following that, a second standard was established that uses OFDM modulation techniques and operates in the 5GHz ISM band. It is gaining popularity due to high data transmission rates over short distances, device interoperability, and the improved development of antennas with big bandwidth.

1.2.3 IEEE standard for WiMAX

WiMAX was founded in June 2000 by the WiMAX Forum, with the goal of promoting and certifying interoperability and compatibility with existing standards like as IEEE 802.16 and HIPERMAN. The IEEE 802.16 set of standards, which defines the functions of the physical (PHY) and media access control (MAC) layers, is used to deliver broadband wireless services. It functions similarly to Wi-Fi, except it provides faster data transmission over longer distances and accommodates more users. Fixed 802.16d, defined under 802.16a and sometimes referred to as 802.16-2004, and mobile WiMAX IEEE 802.16e [10] are the two models used. Fixed WiMAX is a type of WiMAX that is used for fixed applications such as DSL and has a data throughput of up to 75Mbps. Mobile WiMAX, also known as 802.16-2005, is a low-cost alternative to cellular services, with data rates up to 15Mbps and a cell radius of 2 to 4 kilometres. Table1.1 shows the frequency ranges used.

1.2.4. IEEE standard for BLUETOOTH

Bluetooth technology was established in 1998 under IEEE standard 802.15.1 by the Bluetooth Special Interest Group (SIG). It is used in Personal Area Networks (PAN) to transfer data between devices over short distances of up to 30 feet using radio waves in the Scientific and Medical radio bands (SIM), i.e. 2.4GHz to 2.48GHz (see Table1.1). There are several versions: The original version, version 1.2, allowed for a maximum data rate of 1Mbps. The second version, 2.0+EDR, had a 3Mbps data speed, while the third version, 3.0+HS, had a 24Mbps data speed. Bluetooth technology uses the Frequency Hopping Spread Spectrum (FHSS) multiple access mechanism to send data at 1600 kbps over 79 channels, each with a 1 MHz bandwidth.

1.2.5. LTE (Long Term Evolution)

In 2004, the Third Generation Partnership Project (3GPP), a telecommunications organisation, launched LTE as a project. Release 8 of the 3GPP specifications contained the first version of LTE. The bands used are 700/1500/1700/2100/2600 MHz, with adjustable bandwidths of 1.4/3/5/10/15/20 MHz and downlink rates of 300Mbits/s and 75Mbits/s [12].

1.2.6. 5G (Fifth Generation)

5G stands for fifth generation, and it is a wireless technology used in digital cellular mobile networks that was introduced in 2019. 5G technology's frequency spectrum is separated into three bands: millimetre waves, mid-band, and low band. The 5G millimetre wave, with a speed of 1-2 Gb/s and frequency ranges ranging from 24GHz to 72GHz, is the fastest frequencies in the 5G mid-band range from 2.4GHz to 4.2GHz [13-14]. This frequency is now the most commonly used, with over 20 networks using it to provide speeds ranging from 100 to 400 Mb/s over the 100MHz spectrum. China uses the 3.5GHz spectrum, while other countries use the 3.3GHz and 4.2GHz bands. Low band employs a frequency range that is similar to 4G.

1.2.7. LoRa (Long Range Radio)- IEEE 802.15.4g

Bluetooth technology has a limited range for local communication and requires more power than other wireless communication technologies. LoRa is an alternative technology that is now being employed in IoT networks. It's a brand-new technology created by a firm called Semtech for low-power and long-range wireless communication. Long Range Radio (LoRa) is a technology used in IoT and M2M networks. LoRa Alliance is an non-profit organisation that develops LPWAN (Low Power Wide Area Network) standards for IoT. This technology has a range of 2-5 kilometres in urban areas and 15 kilometres in suburban areas, with data speeds ranging from 0.3 to 50 megabits per second. It uses a spread spectrum modulation technique to reduce interference. LoRa technology works in the ISM bands of 868MHz (European ISM) and 915MHz (American ISM) [15].

Table 1.1 Different Wireless standards used with frequency of operation and bandwidth

Wireless Standards	Frequency Band of operation(MHz)	Occupied bandwidth (MHz)
WLAN (Wireless Local Area Networks)	2400-2484	84
	5150-5350	200
	5725-5825	100
WiMAX (Worldwide Interoperability for Microwave Access)	2500-2690	190
	3400-3690	290
	5250-5850	600

Bluetooth	2400-2500	100
LTE (Long Term Evolution)	1710-1755	45
	1710-1785	75
	1850-1910	60
	1920-1980	60
LoRa (Long Range Radio) in Europe, India, United States, South Korea	863-870	07
	865-867	02
	902-928	26
	920-923	03
WBAN	2360-2400	40

1.2.8. WBAN (Wireless Body Area Networks) IEEE 802.15.69

WBAN technology supports both inside and outside communication throughout the human body and is employed in medical and non-medical applications. This is a wireless technology that uses different wireless frequency bands for data transmission, such as 400/800/900 MHz and 2.3/2.4GHz, as defined by IEEE standard 802.15.69. This technology is primarily utilised in wearable wireless sensor networks with high data rates (10Mbps), low power consumption, short range, and a maximum of 256 nodes per body region. For channel sharing, it employs the CSMA/CA channel access mechanism [16-17].

1.3. MOTIVATION

With the rapid advancement of wireless communication technologies, there is a greater demand for small devices. Antenna optimization is required to overcome the overall dimensions of such systems. Highly efficient antennas with increased performance features such as wideband, multiband [18], compact size, inexpensive price, and ease of fabrication are required for wireless data transmission at high rates. Currently, wireless devices offer multi-communication by working on several wireless frequency standards, thus researchers are paying close attention to multiband antennas with broad properties and small dimensions. There are a variety of approaches available in the literature to do this, but fractal and defective ground structures are the best theories for achieving such behaviour in microwave and antenna engineering component design. Self-similarity and space-filling qualities are features of fractal geometry. Multiple resonances in antennas can be obtained thanks to the self-similarity property of fractal structures, which also increases the length of electric current flow without increasing the overall dimensions of the device, resulting in a more compact construction. Any H, E, V, or U shape defect in the ground plane that boosts antenna efficiency in terms of gain and bandwidth is considered a defective ground structure. Because Wi-Fi, Bluetooth, Zigbee, GSM, GPS, LoRA, IoT, WiMAX, and LTE/5G are the most widely used wireless communication standards for home automation, medical, and industrial applications, there is a high demand for multiband antennas with high gain, wide impedance bandwidth, small size, and low profile single fed [19].

Narrowband antenna, for example microstrip patch antenna, at present commonly used. The size and results of an antenna are greatly dependent on the frequency of operation and wavelength. As a result of the change in frequency of operation, antenna proposal factors for example gain, input impedance, radiation pattern, surface current distribution, and so on will vary. Antenna dimensions are measured in quarter wavelengths per operating frequency, and these basic design guidelines are followed when creating antennas. However, obtaining compact designs with respect to frequency remains a critical difficulty in antenna design. Fractal and defective geometries can be used to solve this challenge, and they can even be extended to array design to meet the minimum criteria of wireless communication systems. There are number of reasons why fractal and defective geometries are becoming increasingly popular in antenna design. To construct antenna with similar features, several copies of the same design can be built up with varying scaled values [20-21].

Second, because of their space-filling property, tiny scale fractal patterns can be used to better use antenna space [22-23]. The fractal antenna concept is the result of combining two disciplines: electromagnetic and geometry. D.E. Isbell, Du Hamelet, and P. Mayes developed the first spiral and log-periodic antennas in the early twentieth century, and fractal antennas appear to be a suitable choice to solve challenges of antennas working on numerous frequencies with compact dimensions. Defected Ground Structures is another approach that is gaining a lot of interest right now (DGS). The Defected Ground structures are a purposefully created defect on the ground plane of a printed microstrip board. It is typically, created in the form of an etched-out pattern on the ground plane. It is a preferred way for improving antenna properties such as operational bandwidth, gain, and cross-polarization, among others. DGS are ground plan topologies of periodic and non-periodic structures used to redirect current distribution, changing the circuit's reactive characteristics such as inductance and capacitance. Various defective structures have been discovered and used in the literature [24-29]. The circulation along with transmission of current via ground plane must be regulated in carefully choosing the proportions besides forms of defective structures, which in turn affects the creation and transmission of elect magnetic waves through the substrate material. Additional frequency bands can be achieved by variations of the inductive and capacitive properties of the ground plane, resulting in multiband behaviour of circuits, which is highly helpful in wireless communication devices.

Planar patch antennas is designed in this thesis for wireless applications such as Bluetooth, Zigbee, Wi-Fi, LoRa, GSM, LTE, and others with frequencies ranging from 1GHz to 15GHz. To achieve multiband and broad bandwidth characteristics, two distinct antenna prototypes are constructed and tested based on fractal and defective geometry. On Roger RT Duroid 5880 material, the first antenna is built with circular cut truncated edges patch with U-shaped defective ground. With bandwidths of 140, 280, 300, and 340MHz and gains of 5.52, 8.05, 5.32, and 7.87 dB, four resonant frequency bands are achieved: 3.93, 6.81, 10.79, and 11.64GHz. Second, a fractal patch in the shape of an ellipse with a step cut. On Rogers RT Duroid 5880 dielectric substrate, a defective ground antenna is simulated and built. The antenna has three resonance frequencies of 2.6GHz, 6GHz, and 8.2GHz, with S_{11} co-efficient of -18.18, -15.11, -16.33dB and a large impedance bandwidth of 410, 1070, and 4840MHz. The antenna structures proposed are small in size and have qualities such as wide bandwidth, high gain, and multiband characteristics. The antenna has a vast coverage area and an omni-directional emission pattern, making it appropriate for a variety of wireless standards.

1.4. STATEMENT OF PROBLEM

Antennas are an important part of wireless signal transmission; they change electrical impulses into electromagnetic waves and act as a transducer on both the sender and receiver sides. Miniaturizing antennas is becoming more and more important to make handheld wireless communication devices work better. Also, wireless devices like cell phones use a variety of technologies, such as the ISM band for Wi-Fi, Bluetooth, BLE and Wi-MAX, GSM, CDMA, and so on. Traditional antennas only work on one frequency band, but now there is a need to make antennas that can work on more than one frequency band so that only one antenna is needed for a device. The main goal of the thesis is to design patch antennas that can be used in wireless applications and have a wide range of frequencies. The antenna made to be small so that it can be used with Wi-Fi and Wi-max, which can work at higher frequencies (More than 10GHz). Proper design parameters and matching of the impedance will be used to make the antenna. The impedance bandwidth will also keep in line with what the antenna needs to do. The performance of an antenna will be measured by its return loss, gain, impedance bandwidth, voltage standing wave ratio (VSWR), and radiation pattern.

1.5. SCOPE OF PRESENT WORK

This project's main purpose is to develop and build a planar antenna for use in wireless communication applications. The suggested antenna's resonance frequency, VSWR, bandwidth, S_{11}, gain and directivity were optimised using HFSS modelling software, and the methods following were followed to construct a planar antenna employing planar structures.

1.6. THESIS OUTLINE

This thesis reports provide a detailed explanation of microstrip antennas, different methods has been used in the literature to improve antenna performance, various approaches utilised for analysis, plan, optimise, fabricate along with test antenna for wireless applications, and the entire process to achieve the desired goal is divided into the following chapters.

Chapter 1: Explains the various wireless communication technologies that are employed and the requirement of an microstrip antenna. The chapter also covers the thesis' problem statement, goal, and motivation.

Chapter 2: This chapter covers the basics of antennas as well as performance factors like as gain, impedance, bandwidth, radiation pattern, and return loss. It also discusses the structure of microstrip patch antennas, as well as the various feeding methods and analysis methodologies utilised for microstrip patch antennas.

Chapter 3: Provides a comprehensive analysis of the literature on microstrip patch antennas, which are employed in wireless communication systems.

Chapter 4: Discusses the tools required for antenna design, simulation, and the extraction of performance characteristics for antenna performance analysis. Testing equipment such as the Vector network analyzer and the Spectrum analyzer are described in depth, including their operating principles, types, and procedures for measuring antenna parameters.

Chapter 5: In this chapter, the fundamental design concepts used in antenna design, such as Geometries, are thoroughly explained. The various sorts of shapes seen in nature and employed by researchers in the creation of RF components are explored. In addition, the design technique for microstrip patch antenna with truncated edges is expanded, with simulated and measured results compared.

Chapter 6: Wideband microstrip patch antenna design approach and parametric studies are discussed. In chapter 6testing and measurement are used to verify and validate the simulated results for the planned prototype.

Chapter-7: In this chapter, the conclusions gained from this study work are explained, and recommendations for further research are made.

1.7. SUMMARY

The chapter starts through an outline of wireless communication technology, as well as the various wireless technologies that are employed with various frequency bands and bandwidth requirements for effective communication. Further, it discusses the importance of microstrip patch antennas in wireless applications, as well as how the concepts of planar structures can help increase the performance and efficiency of antennas. In the following chapters, there is a brief overview of the research work that was done.

CHAPTER-2
ANTENNA OVERVIEW

2.1. INTRODUCTION

Beginning with ancient smoke signals, telegraphs, and finally electromagnetic signals to transfer information without wires, sharing data successfully between two distant devices has remained a continual issue in wireless communication. In wireless communication systems, a device called an antenna is required to effectively transform electrical impulses into electromagnetic waves. An antenna is required on both the transmitter and receiver sides of wireless devices to relate electrical energy to radio waves in order to carry signals through air at high speeds without using wires. They provide a straightforward means of transmitting signals in situations where other methods are impractical. Researchers' main concern is to increase the quality and effectiveness of long-distance communication by employing various strategies to improve data delivery. At both the transmitter and receiver ends of the radio wave transmission and reception chain, the antenna serves as a gateway. To avoid interference, radio connection quality can be increased by raising transmission power and increasing receiver sensitivity. The antenna community plays a critical role in this regard, designing compact and multiband antennas to meet the stringent requirements of multifunction wireless devices.

2.2. CLASSIFICATION OF ANTENNA

Antenna is classified into various types on the basis of following characteristics:

On basis of pattern of radiation:

Omni-directional antennas, also known as isotropic antennas, transmit or receive signals in all directions, as their name implies. The transmitted power remains constant from antenna having d, distance. Mostly, it is utilized as an reference antenna to evaluate performance of various antenna types [30].

Directional antennas, often known as beam antennas, concentrate radiation in a single direction. It only covers one way rather than all of them. Typically employed in situations where multiple antennas, such as base stations, are required to cover a specific sector. Yagi-Uda, Horn, helical, and other directional antennas are examples.

Antenna polarisation provides information on the polarisation of radiation electromagnetic energy created by an antenna in the far field. Antennas are classified into the following categories based on their polarisation.

Polarised linear Antenna, Antenna radiates electromagnetic waves in a single plane in the direction of propagation. If transmitting and receiving in the horizontal E plan or vertical E direction, the antenna might be horizontal or vertical polarised.

Circularly polarised antennas may transmit or receive E-field vectors in a circle and are known as circularly polarised antennas. Right hand circular (RHC) and left hand circular (LHC) polarisation stands clockwise and anticlockwise rotations, respectively. Its primary application is in satellite applications [31].

Based on Aperture: The antenna aperture is also known as receiving area or effective area, determines how effective an antenna is at receiving electromagnetic radiation signal power.

Wire Antenna: Wire antennas are simple structures made out of long wires suspended above the ground. The length of the wire in such an antenna is unrelated to the wavelength of the radio waves. These antennas, sometimes known as Zigzag antennas, are used to receive long, medium, and short-wave communications. Used in a variety of applications, including automobiles, buildings, ships, and aircraft.

Aperture Antennas: A aperture antenna is a type of antenna with apertures on both ends. Waveguide, Horn, and Slot antennas are examples of aperture antennas. Because of their compact size, these antennas are mostly employed at UHF and above. To have good directivity and efficiency, this antenna's area should be more than $2>\lambda$. Because they can be simply installed on these circuits, they are commonly employed in applications such as spacecraft and aeroplanes.

Microstrip Antennas: An individual Micro-strip Antenna consists of a patch of metal foil of various shapes (a patch antenna) on the surface of a PCB (printed circuit board), with a metal foil ground plane on the other side of the board. Patches come in a variety of shapes, including round, square, rectangular, triangular, and so on. They're compact, light, and easy to combine with microwave circuits, and they're made utilising PCB manufacturing technology. These antennas are utilised in a variety of applications including space, Internet of Things, medical, communication, satellites, and missiles.

Array Antennas: To broadcast and receive radio signals, an array of several antenna antennas is joined together to create high gain. This multi-antenna concept is also known as MIMO (Multiple Input and Multiple Output). Individual antenna signals are merged to increase the total power radiated in desirable directions by cancelling out unwanted radiation power.

2.3. ANTENNA PARAMETERS

Antenna performance is analysed on the basis of following parameters:

2.3.1 Antenna Gain: Antenna gain refers to an antenna's ability to transmit and radiate in a certain direction when compared to an isotropic antenna. Isotropic antennas operate better in one direction than directional antennas. Gains indicate how much input energy is transformed into radio waves in one direction for sending antennas, and how much radio frequency wave is translated into electrical signal for receiving antennas. Antenna gain is the result of antenna efficiency and directivity working together. Radiation characteristics of antenna are a graphical representation of gain in relation to directivity. The following is the gain in terms of efficiency and directivity:

$$G = \eta D \tag{2.1}$$

Antenna gain is usually smaller than directivity in practise.

Gain is of two types:

Power Gain (G_p): It is the ratio of total average powerandappliedinput power across a antenna to the radiation intensity in a certain direction.

$$Gp = \frac{U(\theta,\emptyset)}{Pt/4\pi} = \frac{4\pi U(\theta,\emptyset)}{Pt} \qquad (2.2)$$

Here, Pt is the total power and $P_t = P_r + P_i$, P_r is the Radiated power and P_i is the ohmic loss in antenna.

Directive Gain (G_d): The ratio of antenna radiation intensity in a specific heading direction to the average antenna radiated power is used to calculate it.

$$G_d = \frac{U(\theta,\emptyset)}{Pr/4\pi} = \frac{4\pi U(\theta,\emptyset)}{Pr} \qquad (2.3)$$

Because directive gain is unaffected by radiated power or antenna losses, the greatest value of Gd is the antenna's directivity.

$$G_p = \pi Gd \qquad (2.4)$$

2.3.2 Directivity: Antenna directivity refers to the degree to which an antenna's radiation pattern is directional. Decibels are used to measure antenna directivity (dB). If the antenna directivity is high and the signal will travel a long distance, the antenna's radiation pattern will be more focused or concentrated in one direction. The directivity of an omnidirectional antenna that radiates evenly in all directions is 0 dB. Antenna gain and electrical efficiency are used to determine directivity. It represents the greatest value of its directed gain.

$$D(\theta,\phi) = \frac{U(\theta,\phi)}{Ptot/4\pi} \qquad (2.5)$$

Directivity is defined as follows in the far field over the S-sphere.

$$D = P(\theta,\phi)max/P(\theta,\phi)av \qquad (2.6)$$

D is a directivity value that ranges from 1 to ∞. The following formula can be used to compute isotropic antenna directivity:

$$D=\frac{4\pi}{\Omega A}=\frac{4\pi}{4\pi}=1 \qquad (2.7)$$

2.3.3 Return Loss: In decibels, return loss is a function of transmitted and reflected power. It's generally measured at the antenna's coaxial cable's input. To transfer maximum power, the return loss should be very tiny. Return loss ism is usually expressed in negative numbers and should be as great as possible [31,32]. The value will be large negative, and the return loss will be good. Value The return loss should be as low as feasible for optimal power transfer. The following is how return loss is expressed in decibels:

$$RL\ (\text{dB}) = -20\ \log10\ \Gamma \qquad (2.8)$$

Where | Γ | = is the reflection coefficient

2.3.4 Radiation Intensity: This the is power emitted by an antenna per unit of solid angle U that is independent of sphere's surface in horizontal and vertical planes. Beam direction and beam efficiency in that direction are related to antenna radiation intensity. It is used to measure antenna radiation because of its measuring range independence. Radiation intensity can be calculated using an isotropic antenna as follows:

$$\text{Radiation Intensity } U=\frac{W}{4\pi} \qquad (2.9)$$

A radiation pattern can be created by charting radiation intensity in different directions.

2.3.5 VSWR: This ratio parameter is used to determine how well antenna impedance and transmission line impedance are matched to deliver maximum power. Both terminals' impedances should be matched to transfer maximum power between source and load. When a transmission line is not correctly terminated, the travelling wave is reflected back to the termination end wholly or partially. As a result of the interaction of these incident and reflected waves, voltage standing waves develop along the transmission line. VSWR [4] is the ratio between transmitted and reflected voltage standing waves in a radio frequency (RF) electrical transmission system, as seen in Figure 2.1 below.

$$VSWR = V_{max}/V_{min} \qquad (2.10)$$

$$VSWR=\frac{1+|\Gamma|}{1-|\Gamma|} \qquad (2.11)$$

If the VSWR is low, the antenna and transmission line are correctly matched, and more power is supplied with no reflection.

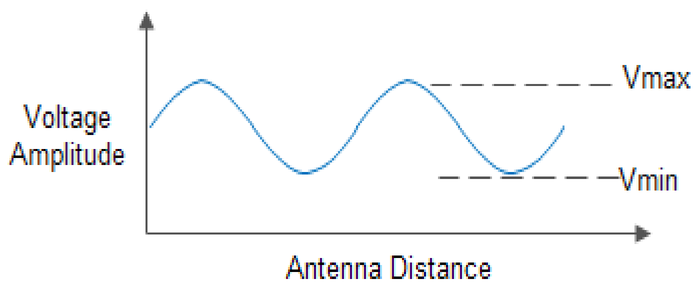

Figure 2.1 VSWR measurement along Transmission line

2.3.6 Bandwidth: It's defined as "the frequency range within which the antenna's performance, in terms of some attribute, conforms to a set standard." It's the frequency range on both sides of the cutoff frequency when antenna performance metrics like input impedance, radiation pattern, polarisation, and beam-width are acceptable in relation to the centre frequency.

2.3.7 Radiation Pattern: The variation of the power radiated by an antenna as a function of the direction away from the antenna or other sources over angular direction is described by the antenna radiation pattern or far field [33]. Radiation patterns are graphical representations of antenna dispersed power emitted from antenna when antenna is broadcasting and incoming energy when antenna is receiving as a function of direction angles when antenna is transmitting and receiving. It might be a three-dimensional or two-dimensional graphic. The parameters are as follows:

Main lobe: As per the Figure 2.2, a major or main lobe comprises the majority of radiated energy over a greater area. Only this section of the antenna emits the most energy, indicating antenna directionality.

Side lobe: Antenna power that is dispersed sideways in relation to the main lobe is referred to as minor or side lobes. In this area, the majority of the antenna power is squandered.

Rear lobe: The back lobe of an antenna is the power radiation lobe that is opposite the main lobe. This lobe also wastes antenna power because it reflects energy in the opposite direction.

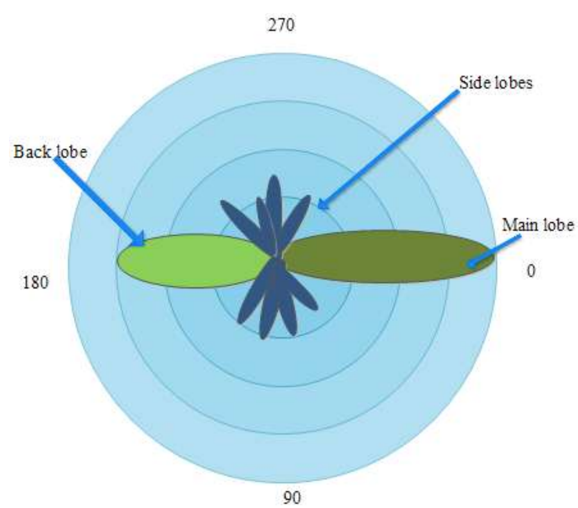

Figure 2.2 Antenna radiation pattern

2.4. INTRODUCTION TO MICRO-STRIP PATCH ANTENNA

These days, microstrip patch antennas are gaining popularity in wireless communication applications. This antenna first appeared in 1953 and was widely utilised in the 1970s for a variety of purposes. Because of circuit printed technology, they have become quite handy. At the same time, its lighter weight and simpler profile make it more appropriate for satellite, spacecraft, and mobile applications than other antennas such as dipoles and parabolic reflectors. The profile of a microstrip patch antenna is fairly simple, as it consists of a metallic area above the dielectric substrate and a ground plane on the other side. Copper or gold are commonly used in microstrip antenna patches and ground materials. Antenna patches can be round, square, rectangular, triangular, semi-circular, and other shapes. On the dielectric substrate material, the patch and feed line utilised to excite the antenna are photo etched. The dielectric material utilised and the physical dimensions of the patch antenna determine its performance characteristics.

Microstrip patch antennas have numerous advantages and applications over traditional antennas. Traditional antennas are bigger, have integration issues, and are not capable of multiband operation. Micro-strip antennas feature a Planar surface, are easy to integrate with microwave RF circuits, are low in weight, and have dual and multiband properties thanks to PCB (Printed Circuit Board) technology. The resonance frequency, radiations, and polarisation of these antennas are all adjustable. By integrating components like as diodes, shorting pins, and placing loads between the patch and ground plane, varied radiation patterns, modes of operation, and polarisation can be created. Instead of several benefits, it has a number of drawbacks, including limited bandwidth, low power handling, high ohmic losses, low gain, undesired radiations, and low efficiency [33].

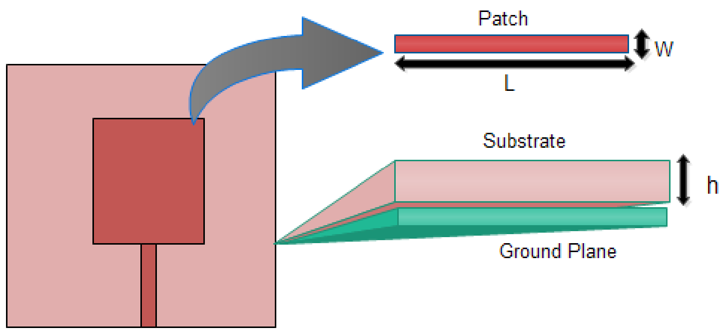

Figure 2.3 A Typical Microstrip Patch Antenna

Small bandwidths may be preferred in some applications, such as security systems, but by raising the substrate height, antenna efficiency of up to 90% can be reached without addressing surface waves, and bandwidth of up to 35% can be attained. The main component of an MPA is a very thin metallic strip patch.

The antenna patch is selected to maximise the patch's radiation pattern, which is achieved by correctly activating the antenna mode [34]. Due of the patch's limited dimensions; the antenna suffers from border fringing. In an x-y planar antenna, fringing is a function of L/h and substrate value. In its place, there are a slew of benefits. Micro strip patch antennas have various limitations in terms of strength and bandwidth. The majority of the study is focused on alternate antenna gain and bandwidth methods. The use of a Micro-strip Patch antenna in wireless applications is also depicted in Figure 2.4.

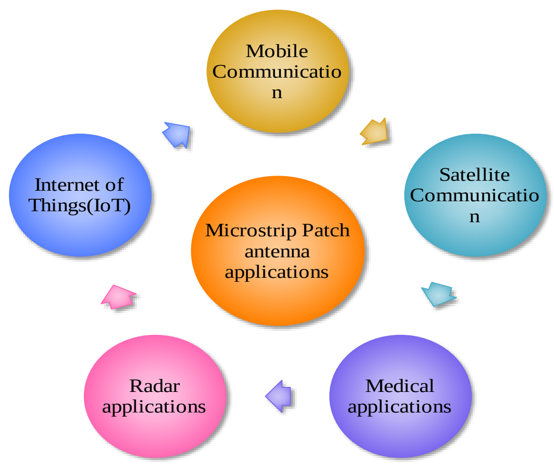

Figure 2.4 Applications of Microstrip Patch antenna in different fields

2.5. MICRO-STRIP ANTENNA FEEDING TECHNIQUES

To convert electrical signals to radio waves, the antenna is energised using several feeding methods. The benefits and drawbacks of different feeding techniques are explained in depth below.

2.5.1. Micro-strip line feed method: Micro-strip feed is similar to patch feed but has smaller dimensions. It is straightforward to design, and its dimensions can be predicted using transmission line theory. Its impedance may be adjusted by adjusting the feed position and each component to fabricate. This strategy, however, has significant disadvantages. The equivalent circuit for this feeding is a shunt RLC circuit with a series inductor representing the feed inductance of the microstrip feed line. Figure 2.6 illustrates the microstrip line feed.

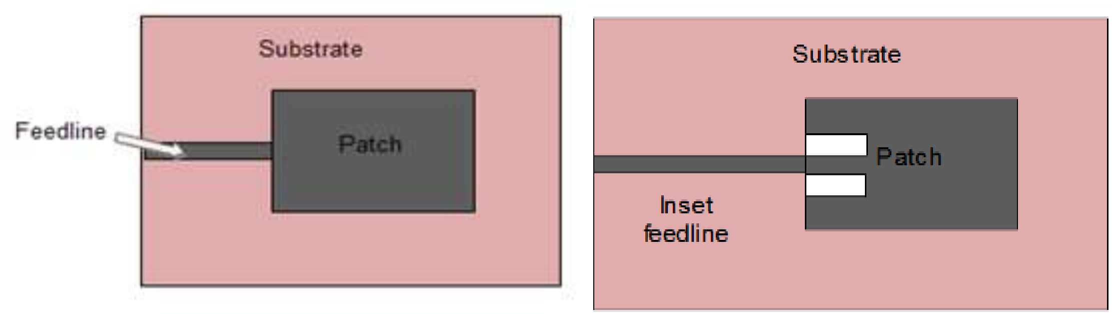

Figure 2.5 Geometry of Microstrip line fee patch antenna [35]

2.5.2. Probe Coupling Method: This technique is also known as coaxial feeding. Electrical signals are connected using coaxial wire. As illustrated in Figure 2.6, this method connects the cable's inner connector to the patch and the outer connector to the ground plane. This approach is simple to build and allows for straightforward impedance matching. It has less spurious radiations than a microstrip feed line. As with the microstrip feed line, the operating bandwidth achieved is somewhat limited. Additionally, this technique is challenging to model in antenna configurations with a thick substrate (t>0.02). Antenna losses increase and dependability is reduced when solder joints are included in the design of antenna arrays. Co-axial feed is analogous to microstrip feed. These two ways generate the dominant mode of operation for patch antennas, but they can also generate higher modes, which generate additional cross-polarization radiations.

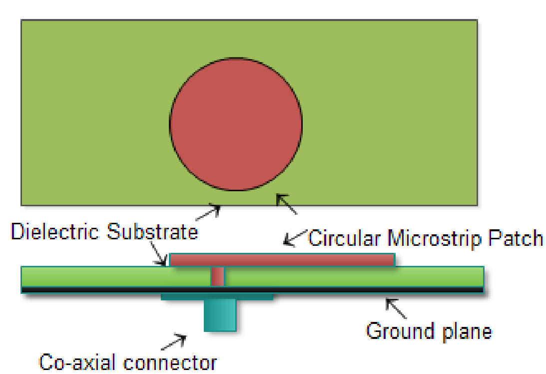

Figure 2.6 Geometry of Coaxial Probe Feed patch antenna [35]

2.5.3. Aperture Coupled Feed: Two parallel layers of dielectric substrate separated by a ground plane are used in this feed method, as shown in Figure 2.7. By designing antennas with a narrow yet high dielectric constant, this method optimises the feed line and radiation functions independently. The aperture size of the antenna is smaller than the resonant size, which results in a rear lobe that is 15-20dB smaller than the main lobe. Because this approach electrically isolates the feed and phase shift circuits, it is advantageous to utilise it in microstrip arrays. It also has a disadvantage in that it requires a multiplayer structure with two substrates, which makes fabrication more difficult and increases the overall antenna thickness. It provides a limited bandwidth. This feed method's equivalent circuit diagram resembles a series RLC circuit with inductance connected in shunt.

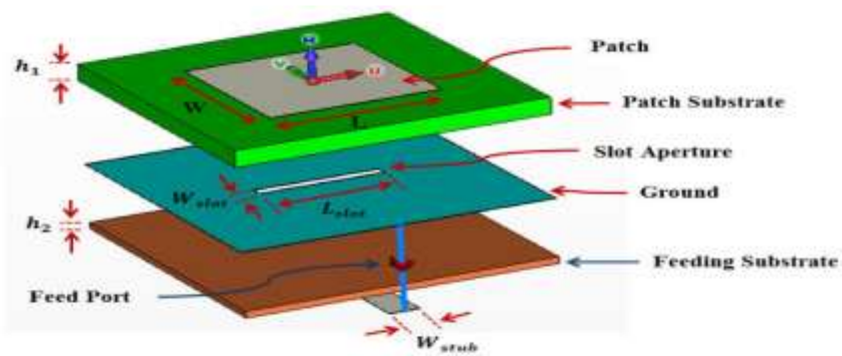

Figure 2.7 Geometry of Aperture Coupled Antenna [35]

2.5.4. Proximity coupling feed: This technique is employed in antenna systems that have two substrates. Due to the lack of electrical contact, this method is also known as the electromagnetically connected feed line method, as illustrated in Figure 2.8. The bandwidth in this technology can be improved by using a thick substrate on which the patch is placed, and to reduce spurious radiation, a thin substrate with a tiny thickness on which the feed line is placed can be utilised. Its manufacture is challenging due to the requirement for accurate alignment of the upper and lower substrates. As with the microstrip and coaxial feed line systems, this method does not require soldering. This method generates capacitive coupling with an RLC equivalent patch circuit and a capacitor connected in series. This approach can achieve a bandwidth of up to 21%.

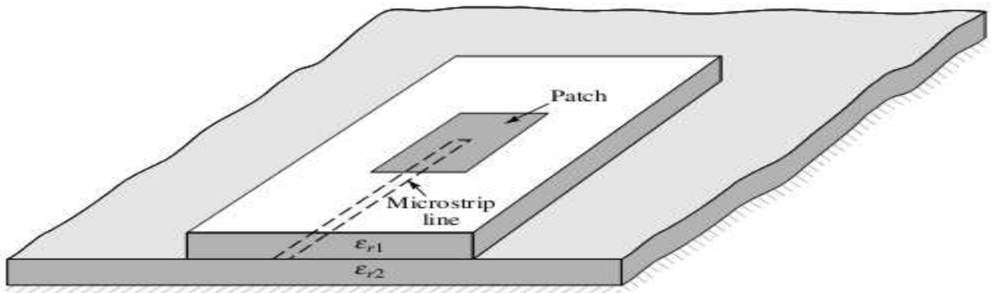

Figure 2.8 Geometry of Proximity Coupled Microstrip Patch Antenna [35]

2.5.5. Corporate feeding method: The most common feeding approach for fabricating antenna arrays is a corporate feed. The incident power is separated and distributed evenly to the individual antenna elements in this situation. This technique can provide power splits of 2k (where k = 2; 4; 8; 16....).

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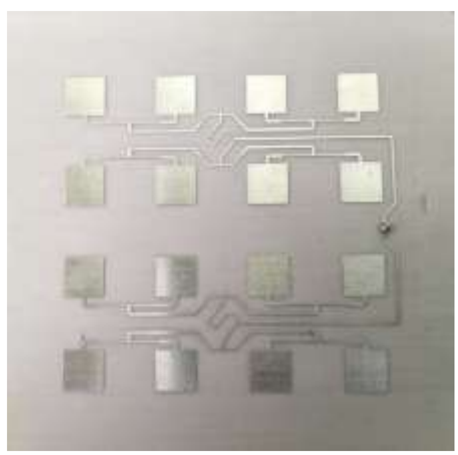


Figure 2.9: Example of corporate feed technique

2.6. MICROSTRIP PATCH ANTENNA ANALYSIS METHODS

Magnetic current distribution (along the patch borders) and electric current distribution are used to classify microstrip antenna analysis methods (on the patch conductor and the ground plane). Three strategies are available based on magnetic current distribution:

- ✓Transmission line model
- ✓Cavity model and
- ✓MNM

As illustrated in Figure 2.9, microstrip patch antenna analysis can be performed using a variety of methodologies, the full wave model, and the cavity model. Among these methods, transmission line analysis is the simplest, making it easiest to model an antenna, but it is also the least accurate. Cavity method is more precise than transmission line method, more adaptable, and provides excellent insight physically, but it is more complex in nature. The complete wave approach is more adaptable and accurate. There are three strategies for distributing electric current:

2.6.1. The transmission line model: This method makes understanding the performance of Microstrip patch antennas much easier. Microstrip is defined as two dielectric substrates, one of which is largely made up of substrate and the other of which is primarily made up of air [35,36]. As a result, because the phase velocities of the substrate and air are different, this technique does not permit true transverse electric magnetic (TEM) transmission. The fringing effect is also taken into account when computing the dielectric constant to arrive at the effective dielectric constant. The following are the effective dielectric constants:

$$\varepsilon_{reff} = \frac{\varepsilon_{reff+1}}{2} + \frac{\varepsilon_{reff-1}}{2}\left[1 + \frac{12h}{w}\right]^{-1/2} \quad (2.13)$$

2.6.2. Cavity model: The area between the patch of antenna and ground plane can be treated as an hollow bordered by magnetic and electric walls on the periphery then from the top and bottom, respectively. These fields are homogeneous across the thickness of the substrate due to the usage of thin dielectric substrates [36,37]. Fields are determined for various patch shapeby integrating the various resonant modes of a two-dimensional resonator. Effective dimensions of antennas should stay greater than physical dimensions. The tangent of the dielectric substrate loss is calculated to account for conductor losses and antenna radiations. Equivalent magnetic currents are utilized to compute the far field and radiated power of an antenna around its periphery. The fringing field and antenna radiated power are only considered at the cavity's edges, not within.

2.6.3. Multiport Network Model (MNM): The MNM can be used for the purpose of analysis of various types of microstrip antennas. The advantage of using this type of model is that it includes the discontinuities in the patch during the process of analysis. In this model there is no need of calculation for the effect of discontinuity rather it is added as a lumped reactance. Multiport Network Model is apprised as one of the best models of micostrip patch antennas. This model consists of several circuit networks which are connected to each other and each of them represents one characteristic of the MPA.

2.6.4. Finite-element method (FEM): The most common application of it is to model volumetric configurations. Based on the planar or volumetric structures that will be explored, the region of interest is restricted to a small number of finite surfaces or volume elements [41]. Divide inhomogeneous wave equations into two boundary value problems to solve them: one for Laplace's equation and another for inhomogeneous wave expressions with inhomogeneous and homogeneous boundary conditions [42].

2.6.5. Finite Difference Time Domain (FDTD): This approach is particularly well-suited for Microstrip antennas due to its ease of modelling the many structural inhomogeneity's that arise none these setups. To find the solution using this method, a time and spatial grid for electric and magnetic fields is generated. Three Cartesian coordinates are considered identical for spatial discretization. The antenna boundary arrangement aligns the borders of the E-cells and assumes that the H-fields are situated in the centre of each E-cell. Each cell has information on the material's properties, and cells near the source are activated using an appropriate excitation function that propagates across the structure. At specified locations, time variations of electric and magnetic fields are calculated. Current is estimated using an integral loop of the magnetic field that surrounds the conductor, with a frequency response provided by the Fourier transform.

2.7. SUMMARY

This chapter is devoted entirely to the fundamentals of antenna and transmission line theory, as well as to the performance parameters of antennas using mathematical expressions for analysis. Additionally, it describes the fundamental model of a microstrip patch antenna, along with its merits and downsides. Additionally, several sorts of feeding technologies are utilised to enhance the gain and bandwidth of patch antennas, as well as various analytical approaches in HFSS such as HFSS and CST. To summarise, this chapter emphasised the importance of microstrip patch antennas.

CHAPTER-3

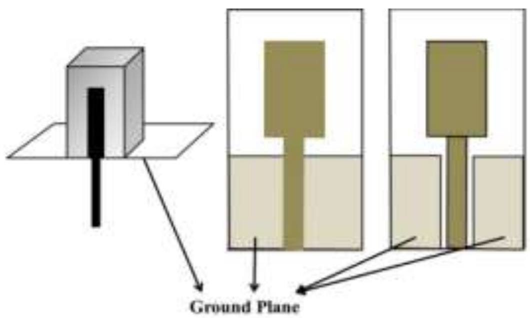
STATE OF THE ART

3.1. INTRODUCTION

The recent and important developments in wireless communication systems, emerges out the need of efficient antenna, to transmit and receive signal wirelessly. The prime reasons for the rapid growth of wireless systems include easy to use, flexible and moreover it is cheaper compared to its wired counterpart. The miniaturization of wireless system technology results in the invention of novel devices such as cell-phone and Bluetooth etc. and the development of new network technologies such as Worldwide Interoperability for Microwave Access (Wi-MAX), Wireless Fidelity (Wi Fi) based on wireless local area (WLAN) networks. For these high-end applications, the multi-frequency and multimode antennas are required and in recent years, the demand of these antennas also increases several times. The prime requirements of such antennas are small size, wide impedance bandwidth, multi-purpose and high gain. The important factors of an antenna affecting the performance of wireless communication system are radiation patterns, polarization, peak-gain, and impedance-bandwidth and mismatch loss. To meet these requirements and improving the performance of antenna with many important factors, the various type of antennas exist in literature are wired, aperture, array, reflector and lens antenna [14]. Although, these are highly efficient antennas however they are large and not compatible with the compact communication devices. Due to compact in size, low cost, ease of fabrication and low profile, the microstrip antenna may be considered the best solution. Henceforth, a lot of research has been done to develop and modify the microstrip antennas.

3.2. LITERATURE REVIEW

(Nyugen, Lee, and Park, 2012; Nyugen, Lee, and Park, 2012; Nyugen, Lee, and Park, [44] developed a CPW-fueled UWB-PMA with triple band characteristics, suggested topologies for ultra-wide bandwidth applications based on coplanar waveguide-fueled printed hexagonal monopoles (Ray &Tiwari, 2008).



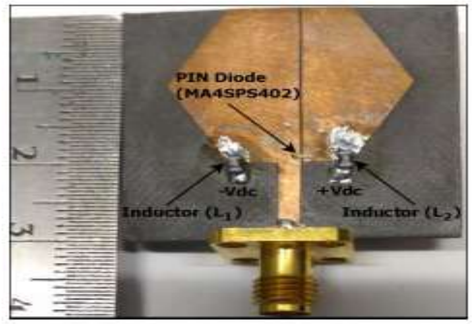


Figure 3.1 Design of antenna 3.2: As per reference design of antenna

The effect of the feed gap on bandwidth is demonstrated using two different feed configurations and a parametric examination of hexagonal layouts. Two printed monopole antennas had their bandwidth and radiating patterns measured [46]. A 15:3:1 ultra-wide impedance for a 2:1 voltage standing wave ratio is provided by a vertically fed hexagonal monopole antenna. The time domain response of the stated antenna design was also examined in the results.

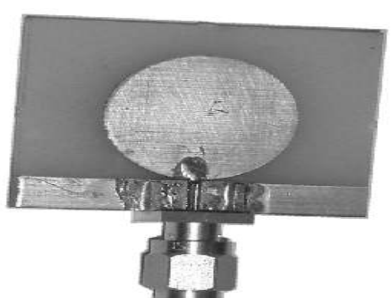


Figure 3.3 Design of proposed antenna Figure 3.4: Proposed antenna

(Cichetti, Miozzi, and Testa, 2017) [47] It is offered a summary of several development processes, materials, and procedures used to investigate and design wideband and ultra wideband (UWB) antennas. On both laminate and dielectric supporting textile substrates, planarity, printability, dielectricity, and antenna wearability can all be achieved. This paper serves as a reference for determining the required bandwidth, field polarisation, gain, size, time-domain response, and materials for use in modern communication systems.

The statistics from the Envelope Correlation Coefficient show positive results and a rise in diversity 2018 (Katharine & Ioannis). It is proposed to use a slot-type Ultra Wide Band (UWB) antenna. These antennas are known for their planarity, compactness, and small size. Multiple prototypes operating between the frequencies of 24-53 GHz can be built if the configuration is properly regulated. The majority of the 5G frequency band is covered by this range [48-49].

(Li, Luo, and Liu, 2017) [50] A square-model slot antenna has been developed, which could be employed in future 5G wireless applications. The minuscule size of 0.64 g incorporates an oval radiating patch and is maintained by a 50 ohm line

A few small circular emitting patches have been proposed for the square-shaped slot to provide superior impedance while thinking about the bandwidths of antenna [51].

(Awan, 2018) [52] At 73 GHz, a rectangular patch antenna was developed. Rogers has introduced the RO4730G3 as a novel substrate for high-frequency antennas. The antenna covered an extremely broad bandwidth of 35.41 GHz, extending from 50.86 to 86.27 GHz, and provided complete coverage.

This coverage is for S11 and covers the majority of frequency bands. The antenna had fantastic peak gain of 6.37dB.

In the year 2016 (Wang, Wang, & Yang) [53] An array antenna based on milli-meter-wave dipole has been proposed that is specifically designed for 5G smartphone applications. It measures 8 X 5.5 mm2 and covers the frequencies 24 to 50 GHz, which are likely to be used in 5G communications. The antenna has a minimal along with a broad bandwidth.

(Al-Hadi et al., 2014) [54], demonstrated that the multi-antenna technology was demonstrated using a cell phone as an antenna array. This study builds two buildings, each with eight antennas that function for frequency range of 3.4-3.6 GHz. The structures can show good variety gain in any condition, including uniform and non-uniform situations. The prototype verifies the simulation results. On the predicted frequency range, the fabric has the most significant mutual coupling, with values of around 10 dB.

Zong et al. (2011) [55] developed a printed open-ended slot antenna for mobile applications. This antenna is a mix design, with a microstrip line fed with a circular patch coupled to a twisted strip and the rectangle and circle cut out of a 60mm X 115mm ground plane. This pattern can be found on the patch's top part. The recommended antenna in frequency band of 1.73-11 GHz and has a 6 dB broad bandwidth.

(2017, Zhao, Yeo, and Ong) [56] A planar ultra wideband Multi Input Multi Output along with greater pattern variety and isolation was given.

With no additional decoupling structure, these two antennas trigger separate modes in the ground, resulting in a wide range of radiation patterns and a high degree of isolation. The impedance bandwidths of individual antenna elements are ultra-wideband. For 20 dB, a peak value of 50 dB was achieved. Gains were realized greater than 1.5 dBi. More than 70% of overall efficiencies have been found. The antenna, on the other hand, is supposed to be in an isotropic antenna.

Elfergani et al., (2018) [57] highlighted both cutting-edge technology and the myriad challenges that come with constructing a mobile communications antenna. The designing method explains how different antennas are built for different applications, how alternative approaches to multi-band and wideband model construction are used.

Alimgeer and colleagues (2012) [58] elaborated that the current notion of band indent was improved by inserting invasive strips in different places under the substrate to get twice the results in the 5GHz range. Together with three strips at the bottom of the substrate at precise locations, it increases the possibility of double outcomes in the 5GHz range. Sharp indent groups necessitate larger receiving apparatus. The designers put their talents to the test by deleting unneeded groupings in order to reduce impedance.

Wang et al (2014) 5 G remote interchanges incorporate Multi Input Multi Output antennas, conclusive strength organizations, visible light correspondences, and subjective radio networks, among other improvements. MIMOs, believable vitality associations, visible light correspondences, and subjective radio networks are just a few of the advancements seen in 5 G remote exchanges. Wireless technologies include Wireless-Fedility, Femtocells, VLC, and mm-wave, to name a few. As a result, 5 G systems should be able to assist [60] in running smoothly.

Chen, Wong, and Li (2018) Two UWB MIMO antennas were recommended. Small and covering a frequency range of 3300 to 6000 MHz, these antennas are ideal for future smart phones. Two UWB antennas were built on top of a planar CFIF antenna. The length of a two-antenna block is merely 35 mm. They intend to expand their services to encompass 5-G mobile connectivity along with 5-GHz-WLAN operating in the near future [61].

Alsaif et al., (2018) [62] Presented an revolutionary cross-polarized small antenna for Ultra Wide Band communications. Only frequencies below 6 GHz were covered when 5G was first released. The proposed antenna is appropriate for usage with mobile devices and phones because of small size. The main antenna is a one of a kind array of MIMO antennas that occupies the radio frequency band of 2 to 12 GHz. Two F-shaped structures plus an open ground structure make up this MIMO design. The two antennas are built one after the other at a 90-degree angle. The MIMO antenna's overall dimensions are 14 mm x 14 mm x 0.25 mm. This is suitable to the cell phones and other hand-held devices due to its extremely low structure. The far-field occurrences were expected to be isotropic, and the apex increase was supposed to be 4.8 dB. The suggested MIMO Wire Receiving Framework employs Envelope Correlation Coefficient (ECC) and Gain Diversity.

Aun and coworkers (2017) [63] with a focus on 5G networks, an outline of forthcoming technological improvements in wearable antennas was presented. 5G allows for the deployment of more wearables in large numbers per macro cell or pico cell due to greater capabilities, throughput, decreased latency, and network reconfiguration.

Chen, Wong, and Li are three people who work together (2018) [64] For the following table gadget, suggested merged ultra wide band twin antennas for frequency range 2.3 to 6 GHz in LTE HB/Wi-Fi/5G operation. Experiments are carried out depending on the outcomes that have been simulated.

In UWB MIMO receiving cables, the planar framework's coupled-featured inverted-F reception device is employed, which is easy to update by imprinting on the inside surface of the mobile phone casing. Without the use of external decoupling technologies, great decoupling between two UWB cables spaced by 3 mm and having a tiny overall length of 35 mm (approximately 0.3855-007 at 3300 MHz) is obtained. In the 3300-6000 MHz range, the distance between two adjacent UWB receiving cables is larger than 10 dB, and the envelope relationship ratio (ECC) is less than 0.1. (2019, Umar and colleagues) [65] Develops a new Vivaldi antenna that can accommodate frequencies between 12 and 18 GHz for 5G technology. The results revealed a considerable boost of 10.33 dBi with a bandwidth of 6 GHz. It offers a Vivaldi antenna with an enhanced structure for the 12 - 18 GHz spectrum for fifth-generation (5G) improvements.

The receiver is built on a Rogers-5880 substrate with a dielectric constant of 2.2 and a dielectric thickness of 0.787 mm. In the same way, the basic Vivaldi antenna layout has been examined. With Gain = 10.33 dBi, Bandwidth = 6 GHz, and Side Flap Levels (SLL) = - 19.9 dB, the results show a significant improvement, meeting the 5G standards. 2017 (Wang, Zhang, and Wu) [66] On display was a cluster of UWB millimetre wave dipole antennas. It causes a large increase in temperature as well as semi-bidirectional radiation beams. A linear phased cluster with eight curved elliptical bow tie antenna elements was developed on a Rogers RT5880 substrate at the top of the PCB portable devices. The antenna's reflection coefficient is not exactly -10 dB in the frequency recurrence range of 26.5 GHz to 40.2 GHz, according to repeated measurements (more than 41.5 percent of the divided data transmission). Large additional and semi-omnidirectional radiation patterns at different filtering sites in the activity band are included in the suggested staged display of antenna radio wire. It has a lot of gain and produces quasi-bidirectional radiation beams. (2017, Hong) [67] I did a quick review of the most cutting-edge 5-G antennas for a variety of applications. It also contains aelaborated schematic of the most advanced 5 G portable antennas for both the sub-6 GHz and mmWave spectral bands.(Hong, 2017) published a summary of current 5-G antennas for mobile applications.(Kumar and Karunakar, 2018) [68], The usage of a printed antenna with two

MIMOs and poor ground construction was proposed. It has band rejection and operates in the WiMAX bandwidth at frequencies ranging from 3.1 to 10.6 GHz. The general structure suggests that transmission capability will be improved, and ultra-wideband technology will be used. The recommended receiving wire is utilised in handheld devices on a daily basis. The antenna radio wire's ultra-wide frequency range (3-10.6GHz) makes it ideal for modern high-tech mobile phones, WLAN, and vehicle antennas. He demonstrated a troublesome printed antenna with a two-MIMO ground structure. It can reject Wi-MAX bands and has a frequency range of 3.1-10.6 GHz. Y. F. Cao et al. developed a planar antenna with a four-band slot for use with GPS and WiMAX. For antenna design, a T-shaped feed patch with two E-shaped stubs and an inverted T-shaped stub is employed. For WiMAX and GPS applications, four frequency bands have been established at 5.2/3.5/2.45 and 1.57 GHz. The vector network analyzer is used to simulate and verify these results (VNA). Simulation and experiment were used to obtain a desirable radiation pattern, return loss, gain, and antenna efficiency [69]. The start shaped slot's rectangular slots are used to efficiently transmit electricity between two layers of the lens. The position of the focusing beam isn't taken into account. When compared to a single layer, the proposed approach offers a two-fold reduction in lens foot print. The antenna design technique, as well as the antenna's performance parameters, which are obtained through experimentation, are thoroughly detailed. Because of its VSWR of less than two, the suggested antenna has a 4 percent bandwidth. The scan loss is less than 1.65dB, and the antenna scan range is less than 33 [70]. Inseop Y et al. described a method for creating a system with beam shaping properties based on the MM Wave and Multi-Patch. When polarised waves collide with the proposed device, they emit a substantially narrower pattern [71]. B.L Zheng et al. proposed higher harmonic modes as an approach for making a multi-mode resonator. The concepts are supported by a slot loaded duplexer and cavity filters. The Sharp out of band skirt demonstrates compact dimensions, wide band filtration, and a low profile form. With less than 20dB rejection, the upper stop band of 6.5GHz to 10GHz is well reached. A duplexer with a wide band filter structure has been created, allowing for channel to channel isolation of more than

30dB. Because the measured and simulated findings are in good agreement, the performance has been validated [72]. N.W. Liu and colleagues created an antenna prototype which was made and measured to evaluate various fed microstrip patch antennas. The article examines a low-profile broad band differential fed MPA. A short slot is added to the patch's corner to reduce the inductance caused by the shorting pins. According to the paper, under dual mode resonance, the radiation pattern is stable and the impedance bandwidth is large. The gain and radiation pattern were, comparable with the results of the modelling. A microstrip antenna with a planar shape and a height of 0.029 has a bandwidth of 13% [73]. Sharma, M. in the article described about an multi band antenna for wireless applications like Bluetooth, WiMAX, WLAN. Radiating patch encompasses a glass shape and a rectangular ground plane. There's an in depth agreement between simulated and measured results which is obtained by fabricating prototype. Proposed antenna come across the requirement for the said applications with numerous advantages such as small size, good radiation pattern and high gain [74]. Mansouri B. et.al. describes an PIFA which is designed in two stages which gives more omni-directional pattern and provides improved reflection coefficients. The antenna can be used for indoor and outdoor wireless security applications. A slot was incorporated to increase the bandwidth [75]. Ahmad, S. et.al. presented in the article an small size ultra-wideband monopole antenna which is having good gain and efficiency. The simulation was done by an computer base simulation software. The design of the antenna was a jug-shaped radiator which was fed by a coplanar waveguide method with the help of FR-4 substrate. The parametric studies were incorporated to achieve maximum bandwidth along with the best gain. The designed antenna may be used for portable wireless devices [76]. Shiquan Wang et. al. presented a novel miniaturized triple-band planar monopole antenna combing single-cell meta material structure and defected ground plane which radiates omni-directional radiation pattern. In it multi resonant meta-materials are used to get tri band characteristics of antenna with the help of defected ground plane. This antenna can be used for WLAN and WiMax applications [77]. Awan, W.A et.al. described a compact and simple reconfigurable antenna with wide-band, dual-band, and single-band operating modes. In this article an p-i-n diode is used for the pupose of switching. The antenna is used for the wireless applications such as WLAN and WiMax [78].

Using various performance improvement strategies, a super wide band Vivaldi antenna was proposed for lower 5G bands in Sub-6 GHz and satellite applications. Different slots are used in the Vivaldi antenna not only to boost gain and directivity, but also to achieve the operating frequency in the desired frequency range. The sweep parameter approach was used to choose all of the dimensions of those slots. At the cutting edge of wireless communication, we want to improve two fundamental characteristics of communication systems: service quality and cost. The suggested antenna has a simple shape and is compact in size, measuring 45 35 0.79 mm^3 [79].

A novel microstrip patch antenna array with a double meander dipole construction with good gain and wide bandwidth is proposed. The twin meander dipole array construction was able to produce two in-phase resonant frequencies in the Ku-band (12–18 GHz), resulting as increased impedance bandwidth without the need for additional design sections. Furthermore, by using a double-layer substrate approach, the array's gain was increased by 2 dBi over the full working frequency range. The E33 type LPKF prototyping PCB machine was used to make the suggested antenna [80].

This research proposes and constructs a multiband branch antenna based on the Chinese traditional pattern structure. The structure of antenna radiator is a symmetrical rectangular stub fused with a Chinese classical pattern structure, with the outer and inner stubs connected to each other to form numerous frequency bands. The ground plate is a trapezoidal shape constructed by subtracting two triangles from a rectangle, and the feeding mechanism is microstrip line feeding. The antenna's overall size is 60601.6mm^3, and the dielectric board is made of FR4. The dielectric constant of the substrate is r=4.4, the thickness is h=1.6mm, and the dielectric loss tangent is tan=0.02. HFSS electromagnetic simulation software is used for antenna modelling and parameter optimization. According to test results, the antenna can cover 1.49 to 1.60GHz, 1.87 to

2.51GHz, and 4.63 to 5.34GHz, and generate three primary frequencies: 1.57, 2.15, and 5.06GHz [81].

The term "multiple-input multiple-output" (MIMO) refers to a system that uses more than one antenna to broadcast and receive data packets. Due of the limited space available in modern compact devices, MIMO antenna elements must be arranged near together. An unfavourable coupling occurs between the closely spaced antennas, causing the antenna properties to deteriorate. The system operates for frequency band of 2–13.7 GHz. The antenna elements are close together, with a 3 mm gap between them. The isolation has been enhanced and is now less than 20 dB across the whole operating range. The antenna's primary performance metrics are unaffected by the addition of the decoupling network. The system is built on a FR-4 substrate, which is affordable and widely available. The corresponding circuit model is also offered to help understand how the suggested system works. Different radiating modes and inter-mode interaction are studied as well as calculated to effectively depict the proposed system [82].

This article shows how to make a miniaturised ultra-wideband multiple-input multiple-output two-port antenna with good isolation using FR4. The antenna is merely 18x28x 1.6 mm^3 in length. High isolation and good impedance matching are accomplished by loading three crossed X-shaped stubs between two disconnected ground planes. This UWB MIMO antenna's working frequency band is 1.9–14 GHz, and the isolation is preserved at 20.2 dB throughout the analysis frequency band [83].

A printed monopole antenna with several resonance frequencies was presented to cover a wide range of applications. The monopole antenna resonated at 4.24GHz to 5.04GHz with an 800MHz bandwidth and 6.34GHz to 8.24GHz with a 1900MHz bandwidth after inserting a stub with the partial ground. Resonant bands were enlarged in the range 4.37GHz to 5.22GHz, 6.11GHz to 7.80GHz, 9.49GHz to 10.41GHz, and 12.11GHz to 13.06GHz when another asymmetric stub was inserted, with a return loss of almost -20dB in all bands. The ground plane was replaced by a metasurface planar structure to improve return losswith bandwidth ranging from 900MHz to 4310MHz and maximum gain of 1.9 dB achieved, allowing the monopole antenna to be used in C, X, and Ku band applications such as satellite communication, weather radar [84].

The innovative wideband partial ground plane microstrip antenna and microstrip planar array, intended for huge MIMO systems as base station antennas. This antenna system is proposed to be used in future 5G networks in the sub-6GHz frequency. In comparison to the millimetre frequency band, this band will provide enough coverage. Atmospheric attenuation losses and line of sight issues plague this millimetre frequency. The antenna is made out of a Roger 3003 substrate with a dielectric constant of 3, a length of 50mm, a width of 50mm, and a height of 1.5mm. The microstrip feed line is having width of 2.5 inches along with length of 17 inches. The patch is 17 inches wide and 19.5 inches long. Inset-1 has a width of 0.5 and a length of the, while inset-2 has the same measurements [85].

To achieve the optimum antenna model, many concepts and structures relevant to antenna design were used. The suggested antenna's impedance matching and bandwidth are improved by L-shaped stubs and inverted T-shaped slots incised in the framework. The proposed design has been fed a 50 Ω microstrip line to achieve specific performance parameters of antenna. The various structures of suggested antennas are compared, which shows that the design with L-shaped stubs and inverted T-shaped slots has better response of antenna parameter metrics. With enhanced reflection coefficient and gain, the developed antenna has a bandwidth of 133.04 percent (3.14-15.62 GHz) and 16.96 percent (18.56-2.0 GHz) [86].

A novel planar compact wideband dipole antenna is shown, as well as a new feed arrangement. The proposed antenna's wideband operation is deciphered, and a closed form formula for its design procedure is derived. The retrieved formula is then verified by designing and simulating three scenarios of the proposed antenna.

3.3. SUMMARY

The primary goal of this chapter is to conduct a literature study on microstrip patch antennas for wireless communication applications. The fundamental microstrip antenna structure used in wireless standards is discussed in this chapter, as well as the various methods used by researchers for improving the parameters of antenna like, gain, bandwidth, radiation pattern, and compact size to get the high data transmission rate and gain constraints of a particular standard. This research exhibits the advancement of work as defined in the state of the art after an exhaustive review of the literature. In order to improve antenna performance, it also acts as a catalyst for the development of planar antennas.

CHAPTER-4

ANTENNA DESIGN AND SIMULATION TOOLS

4.1 INTRODUCTION

Antenna design is a herculean and iterative process that entails multiple steps, including antenna software design or simulations, fabrication, and testing. This chapter discusses the methods and tools used to design an antenna, analyse it, fabricate it, and test it. While the process of designing a simple antenna, such as a dipole, is straightforward and the current distribution in the antenna structure can be calculated and measured with reasonable accuracy, this makes it simple for designers to calculate various parameters of antenna like gain, bandwidth, VSWR, and radiation patterns, among others. However, for complex antenna structures, the current densities are difficult to calculate, necessitating the use of simulation tools to analyse antenna performance. Numerous commercial and open source tools for antenna design and analysis are available. FDTD, Methods of Moments and the finite element method (FEM) are the most frequently used techniques.

4.2 SIMULATION TOOL USED

4.2.1 Antenna Simulation Software (HFSS)

The Ansys HFSS version 15.0 is utilized for the design and simulation of high frequency electronic structures such as antennas, RF and microwave components, filters, connectors, and printed circuit boards for use in communication systems, satellites, radar systems, and the Internet of things (IoT). It includes a variety of solvers and a graphical user interface (Graphical User Interface). Through interaction with Ansys thermal, structural, and fluid dynamics tools, HFSS performs a powerful and comprehensive multi-physics analysis of electronics components to ensure their thermal and structural reliability. It is a magnetic tool that is used for research and development as well as virtual prototype design. It is a well-known tool for 3D modelling in high-frequency design. In 1990, Professor Zoltan Cendes developed it with his students at Carnegie Mellon University. This tool combines simulation, visualisation, automation, and solid modelling capabilities. This software optimises performance by utilising the Finite Element Method (FEM), superior graphics, and meshing. The user has the option of selecting the solver that best fits their design requirements.

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansys HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansys HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency, and Fields.

Some uses are given below:

1. **Package Modeling** – BGA, QFP, Flip-Chip
2. **PCB Board Modeling** – Power/Ground planes, Mesh Grid Grounds, Backplanes
3. **Silicon/GaAs** - Spiral Inductors, Transformers
4. **EMC/EMI** – Shield Enclosures, Coupling, Near- or Far-Field Radiation
5. **Antennas/Mobile Communications** – Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Quadrafilar Helix, Specific Absorption Rate(SAR), Infinite Arrays, Radar Cross Section(RCS), Frequency Selective Surfaces(FSS)
6. **Connectors** – Coax, SFP/XFP, Backplane, Transitions
7. **Waveguide** – Filters, Resonators, Transitions, Couplers
8. **Filters** – Cavity Filters, Microstrip, Dielectric

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those

with complex curves and shapes, in a fraction of the time it would take using other techniques.

4.2.1.1 Structure Designing Process

To begin, the designer can create a geometric model by selecting the modeller type. Following that, an appropriate dielectric material such as FR4 Epoxy or Rogers RT

Duroid 5880 with the desired thickness and dielectric constant is assigned to the designed antenna structure. The following steps provide assignment of sources (port line lumped and wave port) and boundary conditions such as perfect E to patch, ground, and Radiations to Radiation box. After defining the boundary conditions for all sheets and solids in the HFSS simulator, a port, either wave or lump, is required to excite the antenna structure. Following structure modelling and validation, the structure solution is configured. Following that, the solution frequency is assigned and a frequency sweep is added to generate the solution frequency over the specified frequency range. Far field setup is included to calculate parameters such as antenna gain and radiation patterns in the far field. After analysing the design, antenna performance parameters can be calculated graphically, via a table, or via a smith chart.

4.2.1.2 Antenna Design steps:

1. Establish the ground plane
2. After calculating with mathematical expressions, create the substrate and assign dimensions.
3. Assign an insulating material
4. Create the patch and assign dimensions to it in order to capture the results of mathematical calculations.
5. Construct a feed line with the appropriate dimensions.
6. Connect the structure together, i.e. patch with feed-line
7. Assign patch, ground plane perfect E boundary conditions
8. Assign an antenna structure a port (Lumped or Wave) to couple electromagnetic energy
9. Create a radiation box and associate it with a radiation boundary.

4.2.1.3 Simulation and Analysis of Antenna

a. To analyse the various parameters of the designed antenna, the analysis setup is created first, followed by the assignment of the desired solution frequency.

b. Navigate to HFSS design—Analysis—Right Click—Add Solution Setup—Assign Solution Frequency—Specify the maximum number of passes

c. Once the solution frequency has been assigned, the next step is to add the frequency sweep that generates the solution frequency across the frequency ranges.
d. Navigate to HFSS design-Analysis-Right-click Setup-Add frequency. Sweep-Select the Sweep Type (Fast)-Assign the start and stop frequencies with the desired step size
e. Following that, a far field radiation setup is used to determine the gain and pattern of the designed antenna.
f. Navigate to HFSS design-Radiation-Right Click on Radiation-Insert far field setup-Infinite Sphere-Enter start and stop values in degrees for Phi and Theta.

Execute analysis setup and compute results in terms of antenna parameters as follows:

Parameters S_{11}: Navigate to HFSS then Design Results and Right-Click to Create Modal Solution Data Report and move to Rectangular Report and Select S_{11} parameters in decibels.

VSWR: Navigate to HFSS Design-Results-Right Click-Create Modal Solution Data Report-Rectangular Report-Select VSWR parameters in the database.

Gain Access: Navigate to HFSS Design-Results-Right Click-Create Far Field Report-Rectangular Report-Gain-Gain Total (dB)

4.2.2 VECTOR NETWORK ANALYZER

As illustrated in Figure 4.1, a vector network analyzer is used to determine the frequency response of active or passive components or networks, or it is an electronic instrument used to determine the frequency dependent properties of the device under test (DUT). This measurement can be performed at any frequency between a few kilohertz and hundreds of gigahertz.

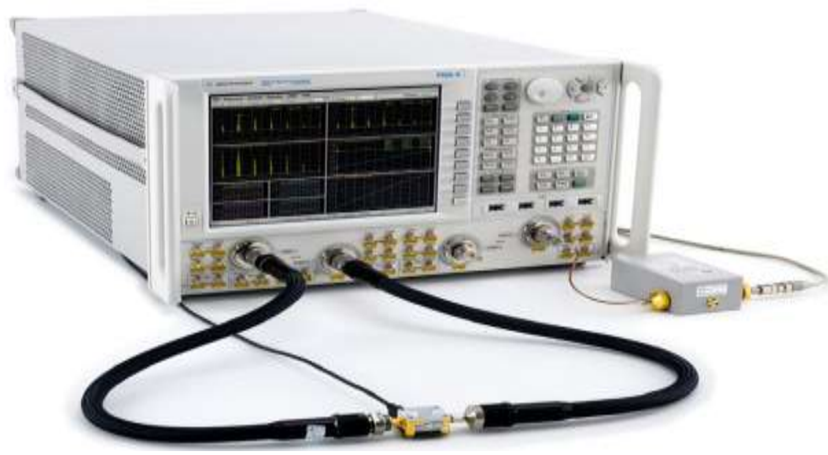


Figure 4.1 Practical two port Vector Network Analyzer

At high frequencies, the VNA measures the power flowing into and reflected back from a component or network. Electrical properties of a signal can be analysed in terms of incident, reflected, and transmitted signals, and thus the DUT's impedance can be calculated. S parameters, also known as scattering parameters, are used to define the ratio of incident and reflected waves. At each frequency point, the amplitude and phase of frequency signals can be determined using a VNA. Additionally, the computer used in the VNA can visualise the insertion and return loss of the device under test in a variety of formats, including real and imaginary, magnitude and phase, and Smith chart. For S_{11} parameter measurement, the setup depicted in Figure 4.2 is considered, which utilises a two-port VNA to measure the DUT's S-Parameters.

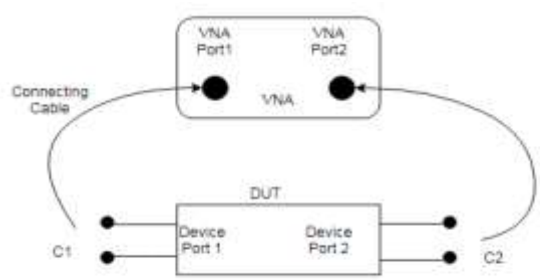


Figure 4.2 Setup for S-Parameter Measurement of DUT

Calibration of the VNA is required prior to performing measurements on the device under test. Calibration entails taking into account and cancelling out all undesired signal reflections caused by connecting cables and end terminals of connectors C1 and C2, as illustrated in Figure. Calibration is required before measurement can be performed. When Port1 is used as a source for RF and a1 is taken as the incident voltage wave on the DUT, b1 and b2 represent the reflected and transmitted waves through the DUT, respectively. The incident wave propagates from the analyser to the DUT, while the reflected wave propagates in the reverse direction from the DUT to the analyser. Due to the fact that the phase and amplitude of a1 are known, the phase and amplitude of b1 and b2 can be determined using a VNA. S-parameters provide an extremely accurate representation of the device's linear characteristics; they essentially describe how the device interacts with other devices when cascaded. The reflection coefficient or S_{11} is denoted in Figure 4.3 as follows:

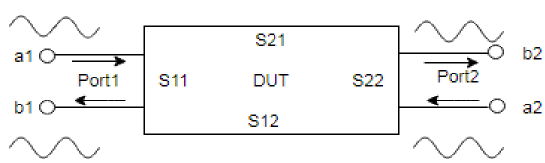


Figure 4.3 S_{11} co-efficient representation for 2-port network

4.2.3. SPECTRUM ANALYZER

Spectrum analyzers are a frequently used test instrument in the field of antenna and microwave engineering. This test instrument provides information about the frequency spectrum of a signal. It determines the amplitude of an input signal in relation to its frequency within the instrument's frequency range. It is used to determine the spectrum strength of known and unknown signals. Spectrum analyzers are used to determine the characteristics of electrical signals, but they can also be used to determine the spectrum of other signals such as acoustic and optical signals. The horizontal axis of the spectrum analyzer displays frequency, while the vertical axis displays amplitude.

4.3 SUMMARY

This chapter discusses antenna design, simulation, and testing tools. The antenna structure can be designed using the High Frequency Software Simulator (HFSS), and the antenna design process is illustrated using a flow diagram. The steps for analysing the performance of a designed antenna in terms of return loss, gain, and radiation pattern using 2-D and 3-D plots are described. Additionally, antenna testing tools are used to determine the performance of antennas in terms of return loss, VSWR, gain, and radiation pattern. The working principle, features, and types of antenna testing tools are discussed in detail.

CHAPTER-5

"X" Band Wide Band Antenna Design

The optimized values of the various antenna parameters are in great demand because of the recent developments in the wireless communication antenna technologies. Due to their low profile and ease of mass manufacture, patch antennas having low profile and low cost are becoming increasingly common [87]. In conjunction with cutting-edge technologies, new wireless communication protocols are currently being launched. Microstrip antennas could be the "Yes" answer for wireless communication, satellite communication and other critical considerations along with various commercial applications in the private and public sectors, such as radio and wireless communication. All the performance criteria are met by the microstrip antenna [88]. Microstrip antennas are amenable to non-Planar and Planar surfaces, low-cost and simple to design, physically resilient, and can be created fast on a printed circuit board utilising cutting-edge printed circuit technology. The ground plane, substrate, and radiating patch are the main components in this technology which plays a major role. Similar to a varactor diode with a changing resonance frequency, placing a load between the ground planes and the radiating patch changes the polarisation, impedance, and pattern. Microstrip antennas could be useful in some government and commercial applications where bandwidth is constrained [89]. To boost the antenna's efficiency, increase the height of the substrate and use a substrate with a lower dielectric constant. The various performance parameters of micro strip antenna like Gain, Return loss, Voltage standing wave ratio, Efficiency, and Bandwidth are greatly influenced by dimensional features of the radiating patch [90]. The antenna's width, length, feed line length, slot or slit cut on the antenna, and the dielectric constant value employed in the antenna's dielectric substrate are all dimensional entities [91].

5.1 BACKGROUND AND RELATED WORK

Y. F. Cao et al. developed a planar antenna with a four-band slot for use with GPS and WiMAX. For antenna design, a T-shaped feed patch with two E-shaped stubs and an inverted T-shaped stub is employed. For WiMAX and GPS applications, four frequency bands have been established at 5.2/3.5/2.45 and 1.57 GHz. The vector network analyser (VNA) is used to simulate and verify these results. Simulation and experiment were used to obtain desirable values of the various parameters of antenna [92]. K. Tekkouk et al. proposed a recent idea in which the operating frequency of this device is 24GHz. The start shaped slot's rectangular slots are used to efficiently transmit electricity between two levels of the lens. The position of the focusing beam isn't taken into account. When compared to a single layer, the proposed approach offers a two-fold reduction in lens foot print. The antenna design technique, as well as the antenna's performance parameters, which are obtained through experimentation, are thoroughly detailed. Because of its VSWR of less than 2, the suggested design has a 4 percent bandwidth. The antenna has a scan range of 33 [93] and a scan loss of less than 1.65dB. Malik et al. described how to use Multi-Patch to create a system with beam shaping capabilities based on the MM Wave. When polarised waves impinge on the proposed architecture, the radiation pattern is substantially narrower [94]. B.L Zheng et al. recommended using higher harmonic modes to create a multi-mode resonator. The Sharp out of band skirt demonstrates compact dimensions, wide band filtration, and a low profile form. With less than 20dB rejection, the upper stop band of 6.5GHz to 10GHz is well reached. A duplexer with a wide band filter structure has been created, allowing for channel to channel isolation of more than 30dB. Because the measured and simulated findings are in good agreement, the performance has been validated [95]. N.W. Liu and colleagues created an antenna prototype that was made and measured to evaluate different fed microstrip patch antennas (MPA). The article examines a low-profile broad band differential fed MPA. A short slot is added to the patch's corner to reduce the inductance caused by the shorting pins. Gain and radiation pattern were likewise found to be in proportion with the results of the modelling. The bandwidth of a microstrip antenna with a Planar shape and a height of 0.029 is 13 percent [96-97].

5.2 CONFIGURATION OF ANTENNA DESIGN

Figure 5.1 depicts the theoretical design of a rectangular microstrip antenna. The three components are a radiating patch, a dielectric substrate, and a ground plane. Round, rectangular, hexagonal, and various forms and sizes are all possible for the patch.

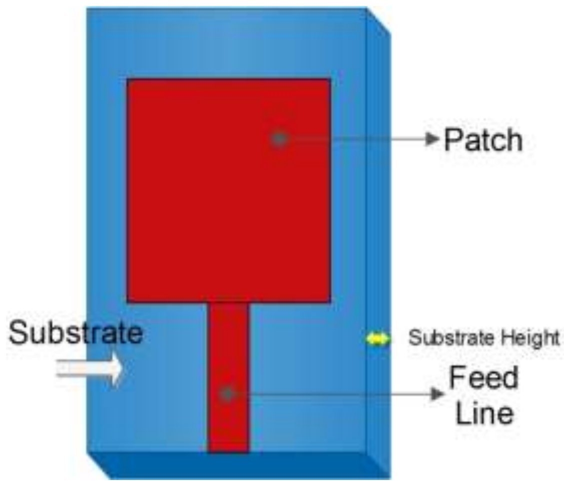


Figure 5.1: Design of the rectangular micro strip antenna

The maximal pattern of microstrip antennas is usually parallel to the patch. End-of-fire radiation is also a possibility in rare circumstances. There are a number of substrate materials to choose from between the ground and the patch, with dielectric constants ranging from 2.2 to 12. In the case of rectangular micro strip antennas, there are certain general guidelines for selecting some of the patch's design elements and others [98-101]. The following are the fundamentals of antenna design. The suggested design uses a microstrip patch antenna with the design parameters mentioned below successfully radiate in the 'X' band.

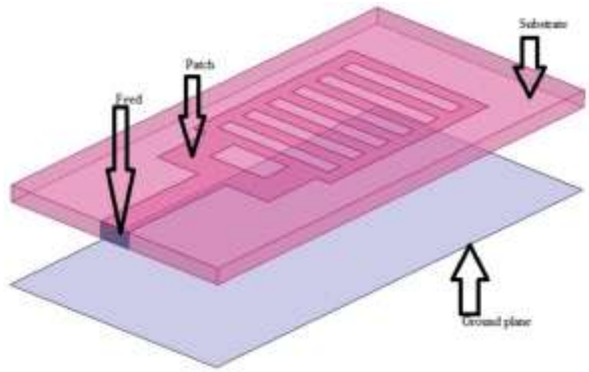


Figure 5.2: View of Patch and ground for suggested antenna design

Figure 5.2 shows a 'Duroid' dielectric substrate with 2.2 relative permittivity and 0.0009 dielectric loss tangents which is sandwiched between the ground plane and the radiating patch. The substrate's height is set at 1.6mm, as shown in figure 2. Multi-slot rectangular patches are utilised for radiation. The dimensions of design are as follows: Figure 5.3 shows the first slot, which is 8mm by 4mm, and the remaining five slots, which are 16mm x 2mm. A lumped port with a microstrip feed line with a width of 4mm and a length of 16mm is shown in Figure 5.2.

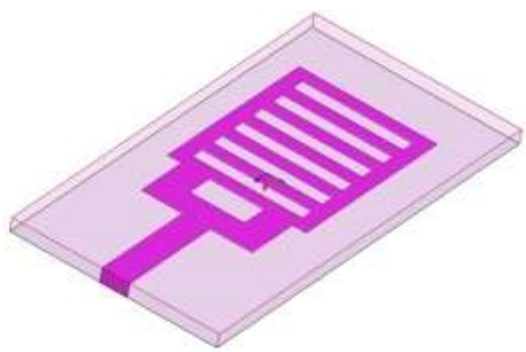


Figure 5.3: Prototype of the patch and substrate of suggested antenna

On the patch, six rectangular slots with the same dimensions and one additional rectangular slot are cut. The chart also includes the dimensions of the various slots.

Figure 5.4. Width of the substrate height depicts 1.62 mm

Figure 5.4 shows how to measure the substrate height with a Vernier calliper. It illustrates that the antenna is built on a 1.6mm thick substrate, as described previously in the antenna design section.

Figure 5.5. Width of the inner rectangle slot depicts 2.01 mm

Figure 5.5 shows the length of the inner rectangle. This represents the projected antenna includes six rectangular elements with an inner length of 2.01mm, as discussed for design part of the antenna.

Figure 5.6. Width of the inner rectangular slot depicts 16mm

Figure 5.7.The length of the exterior rectangle represents 20.12 mm.

Figure 5.6 shows how to measure the width of the inner rectangle with a Vernier calliper. As elaborated in the design of antenna section, the projected antenna includes six rectangular elements with an inner diameter of 16.00mm. Figure 5.7 shows the breadth of the outside rectangle. As presented previously in the design of antenna section, the projected antenna includes six rectangular elements with an outside diameter of 20.12mm. Figure 8 depicts the breadth of the transformer feed line. It shows that, as mentioned in the antenna design section, the desired antenna includes a transformer with a width of 4mm.

Figure 5.8. The width of feed line of transformer depicts 4.00 mm

5.3 ANTENNA FABRICATION AND EVALUATION

HFSS is used to design and simulate the antenna, with the results saved in an excel file. Before being processed further, the file's design is transformed to a DCX file. To build the GBR file a DCX file is used. The GBR file antenna is made on a double-size PCB using the Nvis72 PCB prototype machine. There are also photographs of the fabrication process.

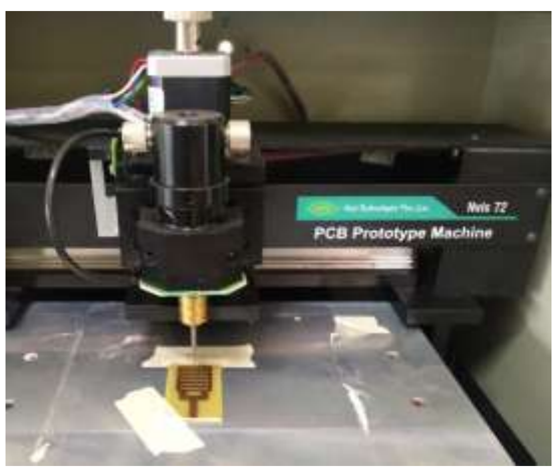


Figure 5.9. Steps for suggested antenna to fabricate on the PCB

The method of developing a double-sided PCB using the Nvis72 PCB prototype machine is depicted in Figure 5.9. The platform coordinates and, as a result, the design of the PCB dimensions can be set using the machine's specific software. Figure 5.10 depicts both sides of the constructed antenna. The first section depicts the patch, while the second section depicts the ground. The dimensions of the patch, ground, rectangular slot, and feed line are the same as in the design section.

Figure 5.10. Fabrication of proposed antenna by using printed circuit board material "duriod"

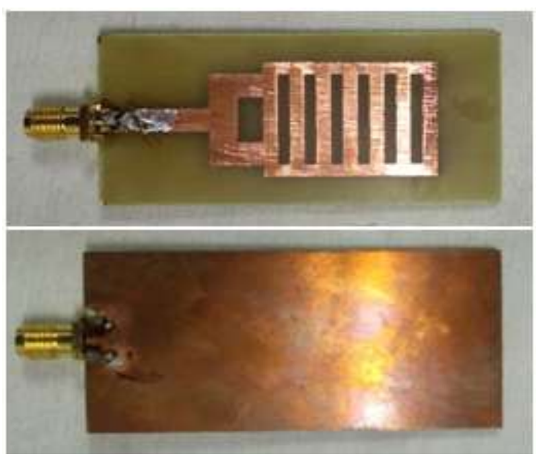


Figure 5.11. Feeding of suggested antenna with connector of 50 Ω

As shown in Figure 5.11, the antenna is fed by a Sub-Miniature version A (SMA) connector. A 50 Ω SMA connector provides the feed to the vector network analyzer. The procedure for keeping substrate height at 1.6mm throughout PCB manufacturing is shown in Figure 5.12. The antenna is then fabricated and tested for various performance parameters using a vector network analyzer.

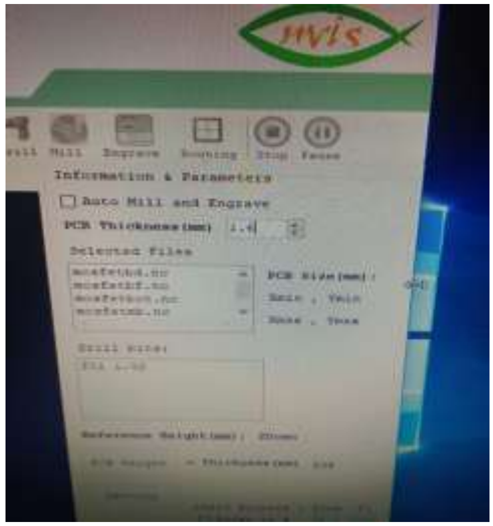


Figure 5.12. Procedure for fabrication of antenna by utilizing length of 1.6mm

5.4 RESULT AND DISCUSSION

Antenna modelling software was used to create the aforementioned antenna, and a vector network analyzer was used to check additional performance aspects such as return loss (VNA). Gain, VSWR, and impedance are among the parameters that the software simulates and reports. Figure 5.14 depicts one of the critical characteristics that affect the antenna's return loss. Return loss is less than -10 dB in numerous frequency bands, including -22dB for the 4GHz range, -25dB for the 8GHz range, and about -21dB for the 11.5GHz range, as shown in the graph. For this design, we're also interested in calculating the additional performance metrics of the suggested antenna at higher frequencies. We'll concentrate our efforts on the higher 'X' band. That is, frequencies between 12 and 18 GHz.

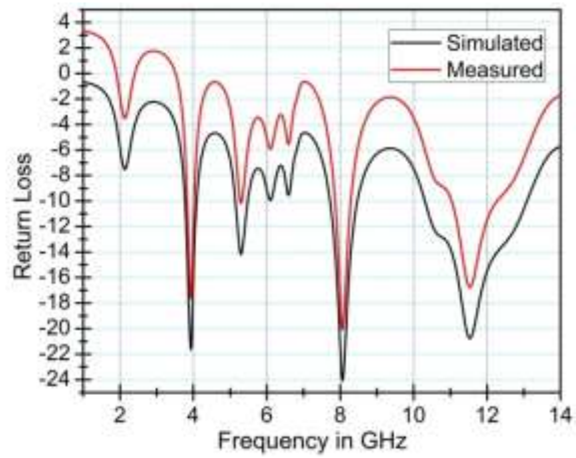


Figure 5.13: Graph between S_{11} and frequency for proposed antenna

Figure 5.13 shows that the S_{11} is less than -10dB for the frequency ranges of 11.2GHz and 12GHz. For a decent antenna, the voltage standing wave ratio must be about one. Figure 5.14 shows that the suggested antenna's VSWR in the frequency range of 12GHz to 13.05GHz is in the range of 1.5 to 2.2.

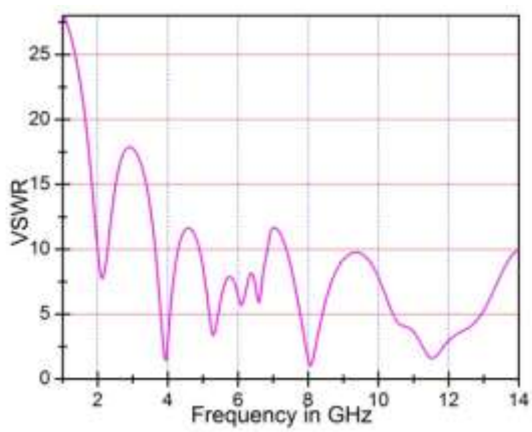


Figure 5.14: Graph between VSWR and frequency

The gain parameter of the micro strip antenna is an important performance component. The gain and efficiency of micro strip antennas are the key drawbacks. In most cases, the gain of a microstrip patch antenna is relatively low. It is very crucial to the antenna's signal gain to be more than 3dB for effective transmission. At 11.5 GHz, the gain is greater than 3dB for phi =240 to 290, and theta is 126 to 146 degrees at this time. The following are different gain values for different phi and theta values:

At phi=240, the gain between theta is 126 and 134 is more than 3dB; at phi=250, the gain between theta is 123 and 142 is more than 3dB. At phi=260, the gain between theta 125 and 143 is higher than 3dB. At phi=270, the gain between thetas 126 and 144 is more than 3dB, at phi=280, the gain is more than 3dB between thetas 126 and 143, and at phi=290, the gain is more than 3dB between thetas 126 and 141. Figure 5.15 may attest to this.

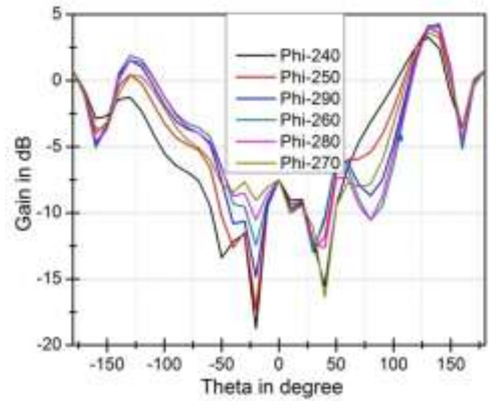


Figure 5.15: Graph between gain and theta for theta -180 to 180 and phi240^0 - 270^0

The following graph is created by plotting the gain with respect to frequency while holding phi at 260^0 and theta at 120^0 to 140^0 fixed. Figure 5.16 shows that the gain is adequately high, with a value of greater than 3dB in the upper frequency band as well. Gain is greater than 3dB, especially at higher frequencies.

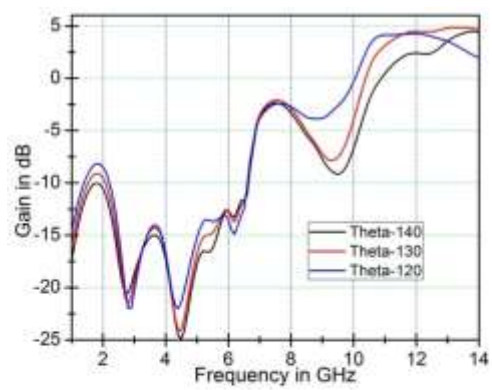


Figure 5.16: Graph between gain and frequency when theta and phi are fixed.

Figure 5.17 shows the efficiency of the proposed antenna as a function of frequency. Figure 5.17 shows that the suggested design's efficiency in the frequency range of 12 GHz to 13.05GHz is greater than 95%.

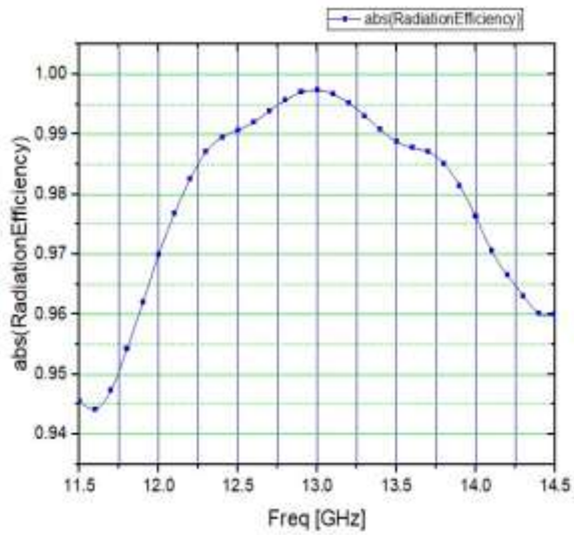


Figure 5.17 Graph between efficiency and frequency

5.5 SUMMARY

Micro-strip patch antenna with multiple rectangular slots is properly designed and tested for higher frequencies in ‘X’ band. Proposed design is having good accord of return loss, voltage standing wave ratio, gain, bandwidth and impedance. Minimum value of the reflection coefficient is found -25dB, VSWR is about 1~3 in between the desired range of the operation, maximum value of the gain is up to 5dB. Efficiency of the antenna is also found more than95% in the range of frequency of operation. It is also interested to note that simulated results are found in good accord with the antenna fabricated and tested results. With reference to the results generated and simulation this can be stated that proposed design can be used for wireless communication especially in the range of 10GHz to 12.5GHz, with sufficient large bandwidth. In between these frequencies all the performance parameter of the antenna is in accord of the desired value. Consequently, this can be quoted that proposed antenna would be having good radiation characteristics if used in any communication application practically.

CHAPTER-6

Bandwidth Enhancement Technique for Next Generation Applications

With the exponential rise of wireless communication technologies and internet services over the last few decades, the demand for high data rate services has increased. As a result, the number of users increased dramatically, and it is clear that massive traffic congestion will be experienced in future communication networks. Good infrastructure is a major problem for manufacturers and service providers to supply additional capacity in networks in order to deliver efficient communication services. Another significant difficulty is the device's compactness. Wireless communication services encounter major issues such as multipath fading, co-channel interference, and delay spread, all of which affect signal quality. With the rapid expansion of wireless communication applications, new design specifications for integrated devices have emerged, requiring more compactness, low profile, and low cost. Antennas play an important role in wireless signal transmission by converting electrical impulses into electromagnetic waves and acting as a transducer on both the transmitter and receiver sides. Antenna miniaturisation is becoming increasingly important to achieve optimised design for handheld wireless communication gadgets, and to do so, PCB technology based microstrip patch antennas have become a buzz word that is attracting research attention for their smaller size, good gain, and bandwidth characteristics. Furthermore, wireless devices such as mobile phones use a variety of technologies such as the ISM band for Wi-Fi, Bluetooth BLE and Wi-MAX, GSM, CDMA, and so on. Traditional antennas primarily work on a single frequency band, but multiple band antennas that can resonate on several frequency bands and eliminate the need for multiple antennas in one device are increasingly required. Antennas must meet the FCC's minimum band criteria for each wireless standard in order to achieve high data transmission rates. The demand for future technologies for fifth-generation wireless communication has been quickly increasing due to the its advantages of wide channel capacity and high data rate transmission [102]. To provide these capabilities, an antenna with a wide bandwidth characteristic is necessary. There are many wideband or ultra-wideband antennas [103-107], but their constructions are complicated. The microstrip patch antenna is one of the most exciting structures that is always chosen to use because of its small size, light weight, low cost, and ease of production and integration [108,109]. The biggest drawback is the low impedance bandwidth, which is frequently less than 5% [110]. As a result, a slew of publications have been published on the process to boost the bandwidth of a microstrip patch antenna by experimenting with various feeding procedures or composition of material. While the patch structure is still being set, a technique called as proximity coupled-feed is used to address the feeding mechanism. The bandwidth can be as high as 8%, however the antenna structure must be thicker than standard [111].

6.1 Experiment and Method of Design:

Figure 6.1 depicts the proposed 4x4 Array X band and Ku band planar microstrip patch antenna. The proposed antenna resonates between 12.1GHz and 13.05GHz, having a total bandwidth of 950MHz. As shown in figure 6.1, the patch dimension is 7.11 x 7.11 mm, the patch to patch dimension (C to C) is 16.2mm or 0.68, the substrate PCB dimension (LxWxh) is 65x65x0.8mm, the transmission feed line is 0.44mm, the Impedance transformer is 0.6 X 4 mm, and the dielectric height (h) is 0.8mm. In this design, the corporate feeding network is used for the first time. Because this substrate PCB material has low dissipation loss and hence delivers good performance and gain, we are utilising PTFE Teflon weaved with d_K=2.2 and loss tangent =0.009.

6.2 Literature Review:

Young-Bae Jung et al. [112] describe a Ka-K band triband antenna. To develop a modified hybrid antenna for the k band, the author uses a Cassegrain reflector with an integrated feeder (HA). For Ku band services, a microstrip antenna with four linear sub-arrays is installed on the HA's sub-reflector to give high gain and quick 2-D scanning capability at a low cost for satellite applications. As a result, the antenna is constructed using a new beam-steering sub-reflector, which is both rotating and flat. To maximise efficiency, a hexagonal structure is constructed with a feeder consisting of 20 dual band horn parts that give dual polarisation. The transmitter and receivers are coupled using feeder horn parts to reduce size. The antenna has been tested in both an indoor and outdoor environment and has an EIRP of 55.2dBW and a GT of 16.8dB for the k band and 7.6dB for the ku band. Microstrip patch antennas have a small bandwidth, which is a significant disadvantage. To improve the bandwidth of an E-shaped conventional patch antenna, author Yikai Chen et al. [113] adopts a distributed L and C circuit design. Low inductance arises in traditional E shape antennas because to probe fed, thus an LC circuit is employed to lower the thickness of air functioning as a substrate. The antenna is designed to work in the AMPS band, which runs from 824 to 894GHz. Simulation findings reveal that the developed antenna has an impedance of over 9% for a voltage standing wave ratio (VSWR) of less than 2 over the frequency range, yet it performs well in terms of radiation pattern within the operating bandwidth. Hussein Attiam et al. [114] show that when a microstrip antenna is coated with a superstrate and placed at the right distance in free space, the gain of the antenna can be increased under certain resonance conditions. To get the highest gain, resonance conditions can be calculated using the suitable transmission method and the cavity model. Adjusting the space between the antenna's superstrate and substrate, as well as modifying the thickness of the substrate, can change the resonance effect. Simulation data and analytical methods are also used to verify antenna performance. Based on simulation findings, the author concludes that the suggested strategy improves antenna performance by 50% over earlier methods. Ramona Cosmina Hadarig et al. propose the employment of electromagnetic band-gap (EBG) structures and artificial magnetic conductors (AMC) to increase antenna performance because of their advantages, such as higher efficiency, higher gain, and lower back lobe and side lobe levels. He created an antenna by combining an EBG with a patch antenna in a single layer and an AMC with a patch antenna in two layers. Because it does not require through holes, the antenna is compatible with plane antenna fabrication technology due to its compactness and resilience. The proposed antenna operates in the RFID 2.48GHz frequency band and has improved radiation qualities without increasing the antenna's size or thickness. Over 23MHz, the proposed antenna delivered bandwidth of 34MHz with EGB and 46MHz with AMC, with gain enhanced from 4.6bB to 5.576 dB over the working frequency spectrum. Feeding methods are significant because antenna efficiency is influenced by how electricity is supplied to the radiating element, whether directly or indirectly [115]. Soumyojit Sinha et al. explain the advantages of microstrip antennas as low cost, low profile, and conformal antennas in their research publication [116]. Antenna excitation is accomplished in a variety of ways, including using a coaxial probe or a microstrip line directly. Because there is no direct metallic contact between the patch and the feed line, various indirect techniques of excitation are used, such as aperture coupling and electromagnetic coupling. The type of feeding mechanism employed completely determines the antenna's input impedance. Using the 1E3D simulator, the author created a rectangular patch antenna that operates in the 2.21 GHz frequency spectrum. A probe is used to feed the antenna. According to modelling results, the antenna is effective in terms of radiation for wireless applications such as mobile portable radios, global positioning systems (GPS), and missile radar. In order to increase antenna bandwidth To further expand the bandwidth of traditional patch antennas, Y. Sung offers a printed wide slot line fed compact microstrip patch antenna with parasitic centre patch in [117]. A 50 ohm microstrip feed line is utilised to excite the slot, and the basic patch design is a rotating square slot resonator. The resonator displays two frequencies: f1 low resonant and f2 high resonant. By inserting a parasitic patch in the centre of a rotatable square slot, the author discovers that low resonance frequency decreases and high resonance frequency increases. The simulation findings show a 1GHz increase in bandwidth. In addition, the proposed structure has an impedance bandwidth of 80% for the 2.23-5.35 GHz bandwidth. S. T. Fan et al. use a pair of parasitic patches to boost microstrip antenna bandwidth in [118]. The antenna is 37mm by 37mm and is made of FR4 material with a thickness of 1.6mm and a relative permittivity of 4.4. Microstrip feed with a length of 16 mm and a width of 2.5 mm is utilised with a pair of semi-circular parasitic patches on both sides to generate additional resonance in the circuit to increase band. A 0.5mm space between the patch and the feed line is maintained to ensure a strong coupling with the feed line. Antenna design is straightforward and simple to construct. For VSWR less than 2, simulation findings reveal a 136 percent bandwidth gain for 2.1 to 11.1 GHz bandwidth. According to simulation results, the suggested antennas can be employed for ultra-wideband modern wireless communication applications. P. A. Ambresh et al. [119] presented a new microstrip patch antenna for wireless applications that is smaller and uses a FR4 dielectric substrate with slots. The proposed antenna is capable of operating at two resonance frequencies of 3.55 GHz and 4.99 GHz. Based on simulation results, the antenna is 18.2% compact for a 270MHZ impedance bandwidth. For a VSWR of less than 2, the antenna displays excellent result in terms of return loss (RL) up to -36.14dB. According to the findings, antennas with linear polarization perform better, and broadside radiation patterns are achieved with less cross polarization.

6.3 Antenna Design:

The proposed antenna resonates between 12.1GHz and 13.05GHz, having a total bandwidth of 950MHz. As shown in figure 6.1, the patch dimension is 7.11 x 7.11 mm, the patch to patch dimension (C to C) is 16.2mm or 0.68, the substrate PCB dimension (LxWxh) is 65x65x0.8mm, the transmission feed line is 0.44mm, the Impedance transformer is 0.6 X 4 mm, and the dielectric height (h) is 0.8mm.

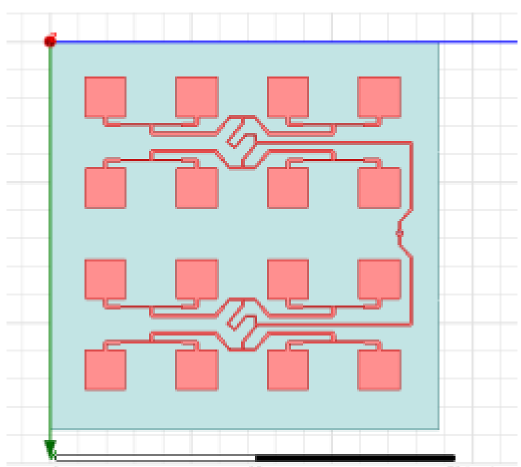


Figure 6.1: Dimensions of the proposed 4x4 antenna array (65mm X 65mm)

As presented in figure 6.2, the suggested design may be easily interfaced to Wi-Fi and Wi-Max devices by employing appropriate SMA or MMCX linkages, depending on the board input type.

Figure 6.2: Application of the suggested antenna array

The RT Duroid 5880 substrate provides uniform dielectric constant from panel to panel and it remains constant for wide range of frequency. Generally, the substrate which has a low dielectric constant will give better performance than the substrate which has a high dielectric constant As dielectric constant increases, the patch dimension, directivity and gain of the antenna decreases. Lowest dielectric constant provides increase in the bandwidth as bandwidth is inversely proportional to dielectric constant. Its gain and directivity is also better in comparison of other substrates. It gives maximum radiation due to its minimum permittivity. Return Loss is much better than other materials for same resonant frequency. Its loss tangent remains constant due to low water absorption. It has highest tensile strength and breakdown voltage so it is not affected by electrical pressure. RT Duroid 5880 is selected for the design of the antenna due to its low dielectric constant and various advantages mentioned above.

6.4 Outcome of the Design

To accomplish the intended performance, the suggested broadband antenna design is built and analysed by using VNA and HFSS software. The moment-based simulator HFSS is used to generate the simulation results. The next section goes over the specifics of the projected antenna feature. The proposed antenna is made with a PCB manufacturing technology and evaluated in an anechoic chamber and with a Vector network analyzer. The manufactured antenna using PCB technology is shown in Figure 6.3.

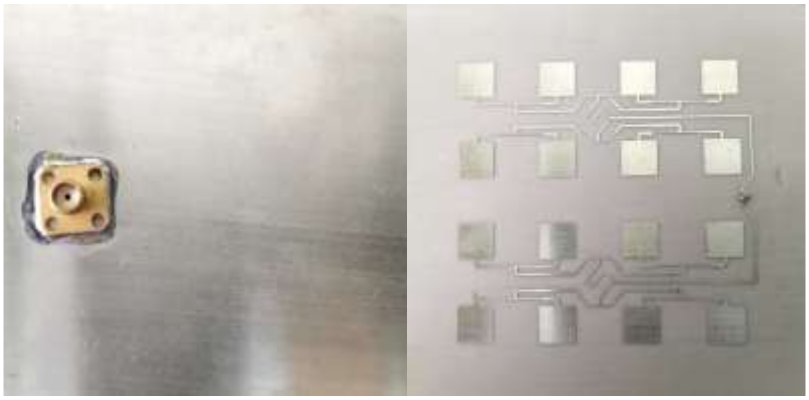


Figure 6.3: Front to back side image for fabricated antenna

Figure 6.4(a) and 6.4(b) shows the testing of the proposed antenna for return loss.

Figure 6.4(a): Testing of the antenna for measurement of return loss

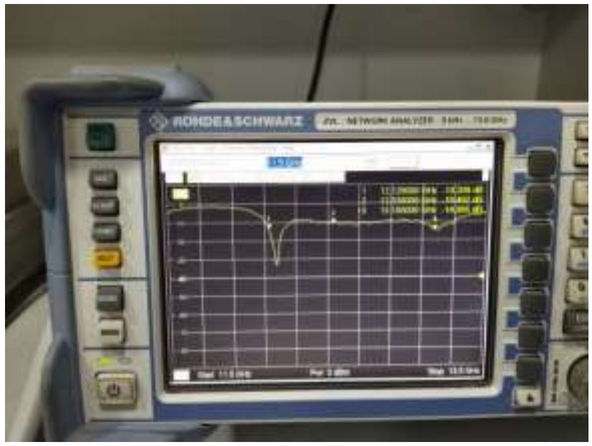


Figure 6.4(b): Testing of the antenna and result for return loss

Return loss can tell you how much bandwidth the antenna has and multi band property of antenna. We compute the bandwidth below -10dB in the vast majority of instances. Figures 6.4(a) and 6.4(b) show that the $S_{11}$is below -10dB for simulated and actual measurements in the frequency range of 12.01GHz to 13.05GHz. This clearly implies that the antenna will radiate efficiently across this frequency range and only a little amount of signal will be returned to the antenna.

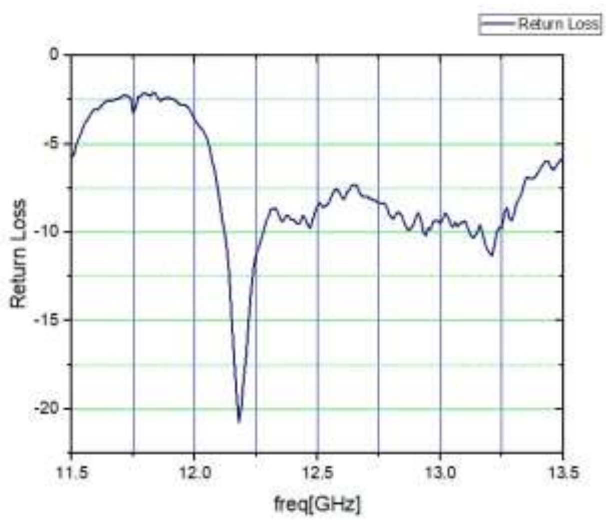


Figure 6.5: Measurement of simulated return loss value using software

Voltage Standing Wave Ratio (VSWR) is a function of the reflection coefficient as well (S_{11}) and it is defined as $VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$.

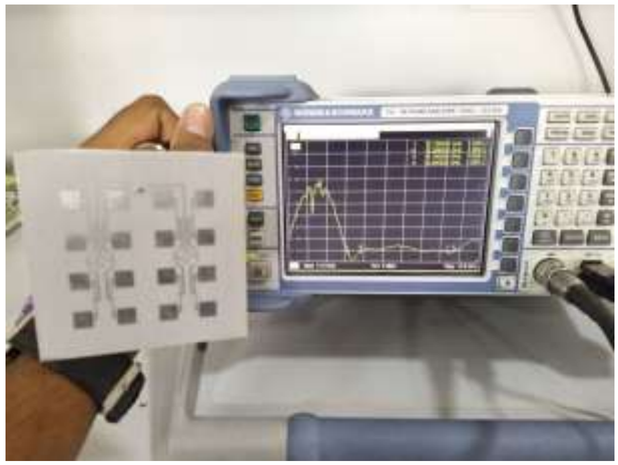


Figure 6.6: Testing of the antenna for measurement of voltage standing wave ratio

Figures 6.6 (Testing of the antenna) and 6.7 (Simulated value of the antenna) clearly show that the measured and simulated standing wave ratio values are in agreement. Within the frequency range of 12.01GHz to 13.05GHz, the value of the VSWR has been observed to be in the range of 2 only during the simulation.

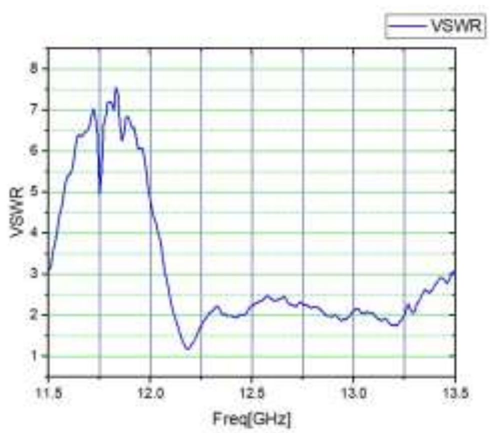


Figure 6.7: Measurement of simulated standing wave ratio using software

Because radiation can travel considerable distances between contacts in the detector material before detection is possible, the detectors are not 100 percent efficient. One of the most important qualities of a detector in radiation measurement is its efficacy. In this industry, gamma spectrometry is one of the most often utilized detector systems, and its performance is strongly tied to detection efficiency knowledge. The percentage of radiation detected by a given detector out of the total yield generated by the source is known as detection efficiency. The electrical parameters of the designed antenna are shown in Table 6.1.

Table 6.1: Designed antenna electrical parameters

Sl. No	Parameters	Obtained Values	Required value
1	Frequency	12.1-13.05GHz	More than 10GHz
2	Bandwidth	950MHz	500MHz
3	Gain	18dBi	10dBi
4	VSWR	< 2	< 2
5	HPBW	18 Deg. (A & E plan)	----

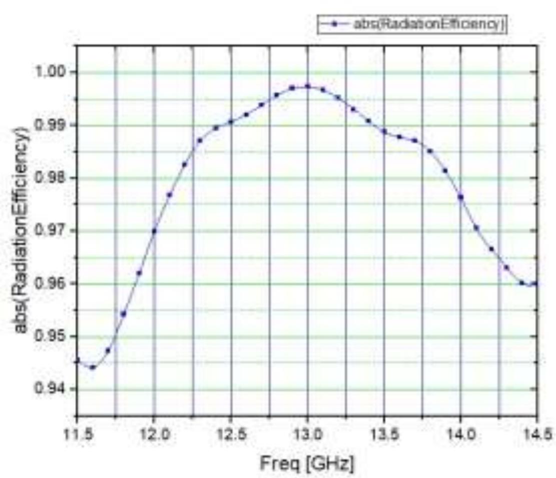


Figure 6.8: Measurement of absolute radiation efficiency

Figure 6.8 depicts the absolute radiation efficiency measurement, which is determined to be in agreement with antenna theory concepts within the frequency range of 12.01GHz to 13.05GHz.Accurately measuring antenna designs and gain may be tricky. Not only does it demand expensive test equipment, but it also necessitates highly experienced and qualified employees. A third difficulty arises from the test equipment itself: interactions between test equipment, test fixtures, and/or equipment holders are impossible to avoid. The majority of microwave component testing differs greatly from antenna pattern and gain measurements. Because it must be performed in an open space with few reflections, this is the case. The three most common antenna pattern and gain measurement methodologies are Far Field Range, Near Field Range, and Compact Range. These devices are inherently unwieldy and expensive, regardless of frequency band. When a Vector Network Analyzer (VNA) or Synthesizer, as well as a Spectrum Analyzer, are incorporated, the price rises.

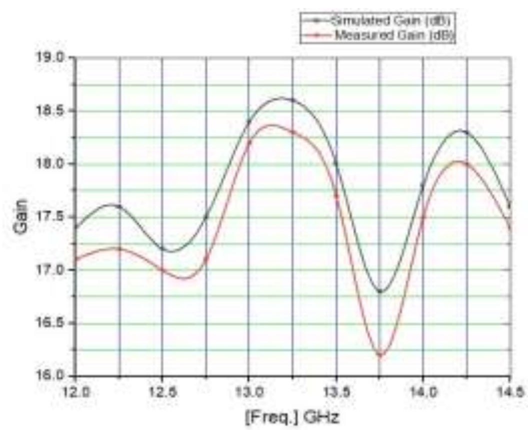


Figure 6.9: Measurement of the simulated and measured gain

The plot of the simulated and measured gain comparison is shown in Figure 6.9. The graph shows that the antenna gain is quite good in the target frequency range due to the computed shape of the proposed antenna. In our design, we intuitively target the frequency range of 12.01GHz to 13.05GHz, and it has been observed that gain between the mentioned frequency ranges is nearly 15dBi. There is mismatch between the simulated and experimental graph of an antenna. The simulation model is an approximation of the real structure. At lower frequencies the small deviations will have negligible effects on the electrical performance of the antenna while the same deviation has a greater effect on the performance. Differences such as at solder joints and line edges are more significant at higher frequencies. The substrate thickness and its permittivity may not be same as taken during the antenna designing in software tool. it may be different for different manufacturer also the permittivity may not be uniform throughout the substrate. Sometimes proper matching of the feed line with the connector is not done and we face the variation in simulated and measured results.

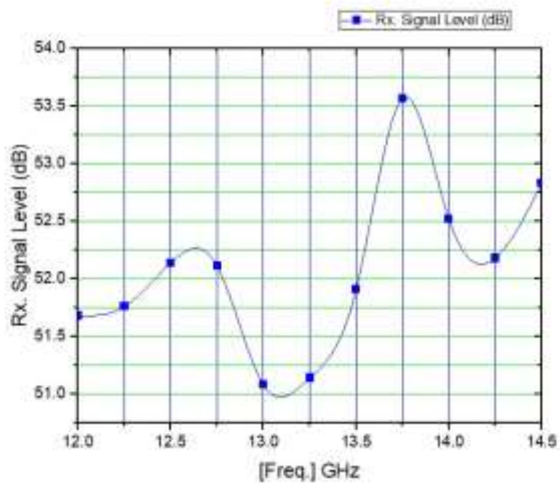


Figure 6.10: Measurement of received signal level

Figure 6.10 shows the value of the received signal as a function of frequency, and it can be seen that the received signal agrees with the conceptual value. The proposed antenna is also compared to a reference antenna [120], and table 6.2 provides the results of the antenna performance characteristics when compared to the literature.

Table 6.2: Designed antenna electrical parameters vs reference literature.

Sl. No	**Parameters**	**Designed antenna**	**Reference literature**
1	Frequency	12.1-13.05GHz	14GHz
2	Bandwidth	950MHz	536MHz
3	Gain	17~18dBi	17dBi
4	VSWR	< 2	< 2
5	HPBW	18 Deg. (A & E plan)	18 Deg. (A & E plan)

Figures 6.11 and 6.12 exhibit a graphical representation of the proposed antenna's azimuth and elevation plane radiation, and it's clear that it's more directed. The figure also shows that the pattern's measured and tested values are in good agreement. The yellow colour graph depicts the simulated or measured value, while the grey colour graphs depict the tested value of the radiation pattern at various angles.

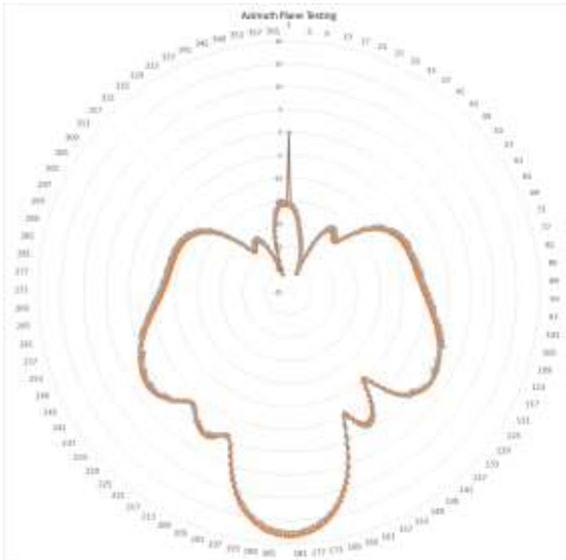


Figure 6.11: Illustration of azimuthal plane radiation (Measured and tested)

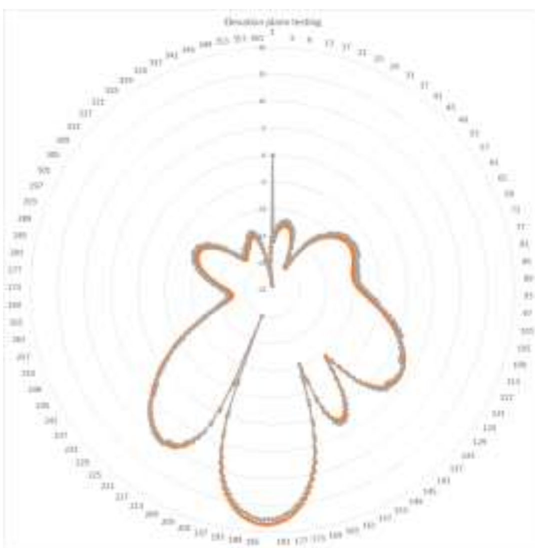


Figure 6.12: Illustration of elevation plane radiation (Measured and tested)

The comparison of previous work and present work is shown in table 6.3 given below

Table 6.3: Comparison of the proposed work with the recent analysis

Ref.	Substrate Used	Operating Frequency Band (GHz)	Gain (dB)	VSWR	Return Loss	Impedance Bandwidth
119	Rogers RT 5880	11.85–15.94	10.2dBi	1to 2	-40.32dB	23.019GHz
120	RT Duroid 5880 LZ	12–18	7.9dBi	NA	below −10 dB	5.2 GHz
122	FR-4	2–13.7	1.1–4.3 dB	NA	>20 dB	Large bandwidth
123	FR-4	1.9–14	0.4-4.8 dBi.	NA	>20.2 dB	NA
124	FR-4	12.11- 13.06	1.9dB	NA	-14.71dB	950 MHz
126	FR4 glass epoxy	3.14- 15.62	5.65dB	NA	S_{11}<-35.62 dB	133.03%
Present work	RT/Duroid5880	12.5- 13.05	18 dBi	VSWR<2	S_{11}<-10 dB	950 MHz

6.5 SUMMARY

Article presented a 4x4 arrays, X-band and Ku-band planar microstrip antenna design with matching almost all the antenna performance parameters. 4x4 array architecture is designed to enhance the gain of the antenna keeping other performance parameters in accord. Designed antenna is operating efficiently in the higher X-band and Ku-band with desired gain, absolute efficiency, and received signal as well. Total operating bandwidth of the antenna is around 1GHZ, and proposed antenna can be used for the applications of Wi-Fi and/or Wi-max of next generation. With reference to the simulation results, it can be concluded that the suggested design is suitable for Wi-Fi and/or Wi-max, particularly in the frequency range of 12GHz to 13.05GHz, and has appropriate bandwidth. Between these frequencies, the antenna's performance parameters are all within the intended range. As a result, it can be stated that the proposed antenna would have good radiation properties if employed in a practical communication application.

CHAPTER-7
CONCLUSION AND FUTURE WORK

7.1 Conclusion

Wideband antennas have become an interesting research area since wireless technology has grown exponentially. Wideband antennas operate in various frequency bands to fulfil the needs of indoor and outdoor wireless communication applications. In X band for high frequency, a microstrip patch antenna having several rectangular slots is correctly designed and tested. The antenna parameters like S_{11}, VSWR, Gain, Bandwidth, with impedance has been found well balanced in the proposed design. The reflection coefficient has a minimum value of -25dB, VSWR is around 13 between the required range of operation, and the gain has a maximum value of more than 10dB. The antenna's efficiency is also found to be greater than 95% in the frequency range of operation. It's also worth noting about simulated results which satisfies with the antenna fabrication and testing outcomes. With reference to the simulation results, it can be concluded that the suggested design is suitable for Aircraft earth station, VSAT, Altimeters, scatterometers, precipitation radars etc., particularly in the frequency range of 12GHz to 13.05GHz, and has appropriate bandwidth. Between these frequencies, the antenna's performance parameters are all within the intended range. As a result, it can be concluded that the suggested antenna would have noble radiation properties if employed in a practical communication application.

A 4x4 arrays, X-band, and Ku-band planar microstrip antenna design was also provided in the research, which matched practically all of the antenna performance parameters. The 4x4 array construction is intended to increase the antenna's gain while maintaining other performance characteristics. The designed antenna provides the requisite gain, absolute efficiency, and received signal in the higher X-band and Ku-band. The antenna's total operational bandwidth is roughly 1GHz, and the suggested antenna can be used for next-generation Wi-Fi and/or Wi-max applications. The various dimensions of the designed antenna was calculated by the author and the results of various parameters of the simulated and fabricated antenna were found along with the verification of the results. The result of the fabricated antenna was found satisfactory as per the objectives of the research work.

7.2 Future Scope

Planar patch antennas have recently received a lot of interest because of their ability to operate over many frequency bands, which is necessary for wireless communication applications. Microstrip patch antennas have a number of drawbacks, including low gain and bandwidth limitations. The goal of this thesis is to look into how to use planar structure to boost the gain and bandwidth of a microstrip patch antenna in order to attain high gain, bandwidth, and compact size. The study is discussed in this section, as well as how it might be developed for future research.

1. The antenna gain, bandwidth, and compact geometry are all investigated in this thesis. The array concept for wireless applications can be used to boost gain in the future.
2. While the antenna prototype was modelled and tested at frequencies ranging from 10 to 15 GHz, its performance at higher frequencies can be assessed in terms of return loss, gain, bandwidth, and radiation pattern.
3. The proposed antenna allows for the measurement of WBAN products' Specific Absorption Rates because it includes ISM frequency bands for WBAN applications (SAR).

Research Publications and IPR:

Following are publication of the research article to fulfil the research objectives. One manuscript is still under consideration with one patent published successfully.

i. **Published Papers**

a. Wide Band Micro-Strip Antenna Design for Higher “X” Band Praveen Tiwari (Lovely Professional University, India) and Praveen Kumar Malik (Lovely

Professional University, India), Source Title: International Journal of e-Collaboration (IJeC) 17(4), Copyright: © 2021 |Pages: 15, DOI: 10.4018/IJeC.2021100105.

b. P. Tiwari and P. K. Malik, "Design of UWB Antenna for the 5G Mobile Communication Applications: A Review," 2020 International Conference on Computation, Automation and Knowledge Management (ICCAKM), 2020, pp. 24-30, doi: 10.1109/ICCAKM46823.2020.9051556.

c. Tiwari, P., Malik P. K., "Design of Planar Wide Band Micro-Strip Patch Antenna for 5G Wireless Communication Applications: Review." (2021).Publisher: Springer Singapore, https://doi.org/10.1007/978-981-16-0733-2_8.

d. Praveen Tiwariet al *2022* J. Phys.: Conf. Ser.2327 012046

ii. Patent

Under process with application number 202111049270

iii. Copyright

Copyrights has been filed with diary No. 23666/2022-CO/L

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APPENDIX A

A.1 ANTENNA FABRICATION

Antenna design is carried out using the HFSS antenna design and simulation software. After converting the HFSS file to Gerber format, the fabrication process of the antenna begins. PCB fabrication technology is used to create microstrip patch antennas. The growing demand for electronic components on smaller boards has increased the demand for PCB fabrication technology. A printed circuit board (PCB) is a board that provides mechanical strength to components and connectivity between them via copper tracks. Single-layer, double-layer, or multi-layer printed circuit boards are all possible. The substrate, copper layers, and solder mask are the three primary components of a printed circuit board. The most frequently used material is FR-4 Epoxy, but due to its high loss, Rogers RT Duroid is chosen for antenna fabrication. The printed circuit board is double layer with 0.35micrometer thick copper layers on both sides. Several steps are required for PCB fabrication. Initially, the design is created on software, followed by the creation of Gerber files. Dip Trace is the software used to create Gerber files. It contains comprehensive information about copper layers, solder masks, and component notation, among other things. The next step is to print the PCB design using plotters, which are specialised printers. It produces a design film, also known as a photo negative. After creating the design blueprint, it is printed on the PCB, indicating where desired copper should be retained and unwanted copper should be removed. This is referred to as etching, and in PCB design, ferric chloride is used to carry out the etching process. Following the removal of unwanted copper, the PCB is washed with an alkaline solution to remove any remaining copper and dried.

A.2 ANTENNA TEST PROCEDURE

After fabricating an antenna using PCB fabrication technology, the performance of the fabricated antenna is evaluated in terms of return loss, VSWR, gain, and radiation patterns. VNAs can be used to determine antenna return loss and VSWR. To determine far field parameters such as gain and radiation pattern, a spectrum analyzer and signal generator, as specified in Table A.1, are required.

Table A. 1 Apparatus used for Antenna parameter measurement

Antenna Parameters	Apparatus used
Return loss (S11)	VNA
VSWR	VNA
Gain	Spectrum Analyzer/ Signal Generator
Radiation pattern	Spectrum analyzer

Instruments used are given in following Table A.2 with specification.

Table A. 2Antenna testing devices used for Proposed antenna Measurement

S. No.	Instrument Name	Company Name	Model No	Specification
1	Network Analyzer	HP	8720A	130MHz-20GHz
2	Signal Generator	Wiltron	68147B	10MHz-30GHz
3	Spectrum Analyzer	HP	8593E	9KHz-26.5GHz

A.2.1 Return loss/VSWR measurement using VNA (8720A)

As illustrated in Figure A.2, the antenna return loss and VSWR are measured using an HP8720A VNA. It is a high-performance microwave network analyzer that measures reflection and transmission parameters over a frequency range of 130MHz to 20GHz with a 100kHz frequency resolution. The VNA may have two or four ports for connecting the DUT (Device under test). Prior to performing antenna measurements, the VNA should be properly calibrated using the calibration kit. The following steps are used to determine the VSWR of the proposed antenna.

Figure A. 1VNA Equipment used for proposed antenna Return loss and VSWR measurement

A.2.1.1 Return loss Test procedure

1. As shown in Figure A.3, connect the test equipment as shown.
2. Turn on the Vector Network Analyzer and select the desired frequency band, i.e. 1GHz for the start frequency and 15GHz for the stop frequency.
3. For VSWR, select the S_{11} parameter. Connect the calibration module to the Network Analyzer to calibrate it. S_{11}/VSWR is the network analyzer's default setting.
4. Connect the feeder cable's other end to the antenna being tested (AUT)
5. Using a VNA, read the response over the band to determine the antenna's VSWR.
6. Take note of the S_{11}/VSWR ratio.

A.2.2 Antenna Gain measurement

Antenna gain is the measurement of antenna power transmitted by antenna under test in a given direction. Antenna gain in given direction is expressed as the ratio of radiation intensity in given direction to the total input power. Antenna gain represents the antenna directivity and antenna electrical efficiency. Proposed antenna gain measurement is done using reference antenna method. Reference antenna considered is LPDA (Long Periodic Dipole Array) wideband antenna. The AUT is placed in far field range of the reference antenna considered. Far field distance is calculated using far field formula given in expression (A.3). Antenna gain measurement is done in free space. Gain of AUT is measured with reference to the power signal received or detected by reference antenna. Both Reference antenna and AUT antenna are mounted on tunable and proper distance is maintained between them for gain measurement. Before antenna gain measurement, insertion losses are measured.

A.2.2.1 Test setup for Gain Measurement

i. Distance ‘D’ between TX (Reference/Transmitting Antenna) and Rx (Antenna under test/receiving antenna) is 10 m.

ii. Cable used is LMR-400/ RG316 (Loss less cable) of length 10 meters.

Formula:

a) Free Space Path Loss (FSPL) = 92.5+20log(Freq in GHz)+20log(Distance D in Km)
b) Total Loss (TL) = FSPL + Measured Cable Loss
c) Gain: (G) = ((FSPL-RSL)/2) or G = Tx Power + FSPL- RSL- G(ref) (A.4)

Where G(ref)= Reference Antenna Gain in dB and RSL is Received Signal Level in dB

a. Calculation of FSPL:

Free Space Path Loss (FSPL) = 92.5+ 20 $\log_{10}$ (Freq in GHz) + 20 $\log_{10}$ (Distance D in Km)

= 92.5+ 20 $\log_{10}$ 14.5+ 20 $\log_{10}$ 0.01 for 14.5 GHz
FSPL = 75.73

b. Calculation of TL:

Total Loss (TL) = FSPL + Measured Cable Loss

= 75.73+ 6

= 81.73

c. Calculation of Gain:

Gain: (G) = ((FSPL-RSL)/2) or G = Tx Power + FSPL- RSL- G (ref)
= 0+ 74.1-51.68-5.3 for 12GHz
=17.10

[Freq.] GHz	Gain Measured
12	17.10
12.25	17.20
12.5	17.00
12.75	17.10
13	18.20
13.25	18.30
13.5	17.70
13.75	16.20
14	17.50
14.25	18.00
14.5	17.40

[Freq.] GHz	FSPL (dB)	RSL (dB)
12	74.1	51.68
12.25	74.3	51.76
12.5	74.4	52.14
12.75	74.6	52.11
13	74.8	51.08
13.25	74.9	51.14
13.5	75.1	51.91
13.75	75.3	53.57
14	75.4	52.52
14.25	75.6	52.18
14.5	75.7	52.83

[Freq.] GHz	UWB LPDA Reference Antenna Gain (dBi)
12	5.3
12.25	5.3
12.5	5.3
12.75	5.4
13	5.5
13.25	5.5
13.5	5.5
13.75	5.5
14	5.4
14.25	5.4
14.5	5.5

A.2.3 RADIATION PATTERN MEASUREMENT

Antenna measurement setup used for Gain and Radiation pattern measurement is same. Radiation pattern of antenna represents the measurement of antenna power density transmitted in particular direction. Antenna radiation pattern measurement is carried out to analyse fabricated antenna radiation in far field region and comparison is done between simulated and measured patterns to validate antenna performance for specific application. For radiation pattern measurement, antenna under test is placed in far field region with respect to reference antenna used.