DESIGN OF MULTI-RESONANCE ANTENNA FOR FUTURE COMMUNICATION SYSTEM

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Electronics and Communication Engineering

BY
RAJEEV DANDOTIA

December 2020

Supervisor(s)
Dr. Ranjan Mishra
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Department of Electrical and Electronics Engineering
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University of Petroleum and Energy Studies
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DECLARATION BY THE SCHOLAR

I hereby declare that the thesis entitled "**Design of multi-resonance antenna for future communication**" has been prepared by me under guidance of **Dr Ranjan Mishra** (Internal supervisor) Professor, Department of Electrical and Electronics Engineering, School of Engineering, UPES, Dehradun and **Dr SM Bhaskar** (External supervisor), Joint Secy & Sc G, NTRO, Government of India. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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ABSTRACT

Wireless communication system has been struggling with spectrum allocation, especially owing to increasing demand of the bandwidth and development of the technological aspects where large bandwidth is required, due to its limited availability. It is also evident that communications have shown deep significance for human and its society since human civilization to recent years.

Electromagnetic spectrum, as we know, is one of the main human sources and antennas have played a fundamental role in the use of this natural source. Many of the constraints in sending and receiving in certain areas were solved despite multiple antennas in techs. In the journey of the mobile communication, GSM, GPRS and EDGE were introduced in the initial generations of development. LTE network, generally referred to as the fourth generation, appears in second decade of the 21st century. This generations paved ways for inventing the Internet on things (IoT) devices and other high bandwidth consuming devices. The fifth generation of network has been used for a new generation of network technology and this 5G, as a mutation of the previous generation would boost delivering high speed and high bandwidth facilities.

The evolving fifth generation technology (5G) integrates the existing wireless interface with future one for higher frequency and spectrum efficiency. Ecosystem design and network system requirement for the auspicious 5G access technique are the leading challengers for the actual deployment of the emergent 5G technology between years 2020 to 2030. International arena has populated multiple frequency bands to populate this communication in prototype phase. Each and every country have been given liberty to decide available band in sub 6 GHz to use for 5G in initial phase. Thereafter, most prominent

band mm-wave is only band which can fulfil the demand of the voracious bandwidth requirement in 5G communication.

The two prominent frequency bands that have been identified for 5G communications are Sub 6 GHz band and mm-wave frequency band. Usability of band depends on environment and electromagnetic characteristics. Each country, according to availability, has been allowed to function the 5G in these two bands. All infrastructure is also been cater keeping of allocated bands.

A radio antenna is an instrument that offers the ability for radio waves to be radiated or received and to further utilised for all primary communication in different spectrum. This is also the most prominent element in the mobile devices where all receiving and transmission depends. The shape, size and design technology is important factor to radiate electromagnetic wave in desired band of the frequency. Keeping view of the size and applications, Microstrip antenna is most popular antenna for mobile communication. The microstrip patch antenna edged over other due to factors like as compact size, integration with devices, ease of fabrication, low cost etc.

Keeping view of the desired bands for 5G applications, as proposed by Governmnt of India, two antenna designs are proposed. These two designed antenna is dedicated for 5G applications in the proposed frequency bands. The objective of the antenna design is to attain multi resonance frequencies in different bands of the 5G communications.

The first proposed antenna is inverted F slot multiband antenna stub matching, and it is designed to operate in sub 6-GHz for the futuristic 5G Communication. The proposed microstrip antenna designed on a single dielectric substrate. An antenna has been design for resonating at three bands with adequate reflection coefficient and bandwidth suitable for LTE-A and 5G cellular applications. The design is loaded with fractal slots along the edge and two inverted-F slotted structure on the patch of the microstrip antenna. The three operating bands chosen for this design are 2.1 GHz, 3.3 GHz and 4.1 GHz respectively, and these bands are as per the frequency regulation adopted by Department of Telecommunication, Government of India. The proposed antenna brand its suitability for future wireless communication in the area of LTE-A and 5G cellular technology.

The second proposed designed is a dual band compact and small microstrip patch antenna meant to operate at high frequency mmWave band of the spectrum. In the proposed design the primary rectangular planer patch structure, powered with microstrip feed line, includes a double concentric split ring slotted configuration on the radiating patch. This structure provides a dual band resonance. The impedance matching is further improved with guided wave slotted structure on the feedline. The antenna demonstrates a dual band resonance precisely at 28 GHz and 36 GHz of frequency. This design at mmWave region of the frequency spectrum communications is feasible for all 5G deployments.

Further, fabrication and measurement processes of both the antennas are accomplished at SAMEER (Society for Applied Microwave Electronics Engineering and Research) Kolkata centre. This organisation is under ministry of electronics and information technology, government of India. All the measured results of fabricated design antenna are compared with simulated results for the validation of the design.

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List of Symbols

A_e : Effective Aperture

B : Channel Bandwidth

c : Velocity of Electro-Magnetic Wave

C : Channel Capacity

ΔL : Length Correction factor

ϵ_r : Permittivity or Dielectric Constant

ϵ_{eff} : Effective Permittivity or Dielectric Constant

f : Frequency of Electro-Magnetic Wave

G : Gain

h : Height of Substrate

λ : Resonant Wavelength of Electro-Magnetic wave

η : Efficiency

S_{11} : Reflection coefficient

Y_{in} : Input Admittance

Z_c: Characteristic Impedance

Z_{in} : Input Impedance

List of Abbreviations

1G : First Generation

2G : Second Generation

3G : Third Generation

3GPP : 3rd Generation Partnership Project

4G : Fourth Generation

5G : Fifth Generation

DoT : Department of Telecommunication

EDGE : Enhanced Data Rate for GSM Evolution

GSM : Global System for Mobile communications

GPRS: General Packet Radio Service

HSUPA: High-Speed Uplink Packet Access

HSDPA: High-Speed Downlink Packet Access

HFSS : High-frequency structure simulator

IMT : International Mobile Telecommunication

ITU : International Telecommunication Union

ITU-R : Radio regulation group of International Telecommunication Union

LTE : Long Term Evolution

LTE-A : Long Term Evolution Advance

mmWave : Millimeter wave

TRAI : Telecom Regulatory Authority of India

WiFi : Wireless Fidelity

WiMax : Worldwide Interoperability for Microwave Access

Chapter 1

INTRODUCTION

> When wireless is fully applied the earth will be converted into a huge brain, capable of response in every one of its parts.
>
> *Nikola Tesla*

The first radio transmission was demonstrated by the Guglielmo Marconi in 1900, and this was the beginning of radio communication era. Since then, multiple new methods and systems were introduced which compel wireless communications to be evolved constantly. A modern era of wireless communication was inbred in 1970s when concept of cellular was introduced, along with the progression in hardware at radio frequency.

In present days, wireless communication is growing with very fast pace impacting the all aspects of human life. Since, 1980, every decade presents a spectator a new age of cellular mobile communication with highly developed technology in terms of data rate of transmission, coverage and spectrum efficiency [1].

1.1 Evolution of Cellular Wireless Generation

In the cellular communication, First Generation (1G) was pronounced in early 1980's. This was an analog based system with focus on voice communication. Low subscriber base is one of its weakness. The Second generation (2G) was introduced in 1990, comprising of digital technology which has presented added features of Subscriber Identification Module (SIM) card, Short Message Service (SMS) and better capabilities such as roaming along with voice communication. Global System for Mobile communications (GSM) was the leading technology for second generation mobile, and the other one is IS-95 and Code Division Multiple Access (CDMA). Improvement of 2G technology presented General Packet Radio Service (GPRS) and Enhanced Data Rate for GSM Evolution (EDGE) that were able to attained data rate of 144 kbps and 384 kbps respectively [2].

In the year of 2000, 3rd generation cellular technology was introduced with new applications and advance features. The initial data rate achieved by 3G technology was 2 Mbps and it was futher improved with the introduction of WCDM, High-Speed Uplink Packet Access (HSUPA) and High Speed Downlink Packet Access (HSDPA) technologies, which improved the data rate up to 30 Mbps. This improved bandwidth efficiency has compelled the researcher to work for higher data rate systems. The 3rd Generation Project Partnership (3GPP) has brought Long Term Evolution (LTE) technology which was the successor of all earlier cellular generations. This was considered as 4th Generation cellular communication and was subsequently followed by LTE-A (LTE-Advanced) with even higher bit rate [3]. This technology enables new dimensions of technologies like Multimedia Messaging Service (MMS), High Divination (HD) mobile TV and Digital Video Broadcasting (DVB) with higher data rate, low latency and high availability wireless networks.

The demand for high volume data traffic has been increased exponentially with other challenges. 4G technology or LTE cellular communication is presently experiencing congestion in terms of network capacity, data latency, shared spectrum, massive device connectivity and quality of service with cost effectiveness[4].

With development of the technologies, it has been evident that 5G communication networks include improved data transmission, low latency, increased network compatibility, and device-centric mobility that are both redundant and secure [5]. The futuristic communication in terms of 5G cellular technology has taken advantage of this wide variety of spectrum for high data speed and more reliable coverage in higher frequency bands. It also helps customers to have with higher mobility. A brief timeline summary of cellular network generation still today is presented in table. 1.1.

Cellular Generation	**Time Period**	**Frequency ranges/ Band**	**Data Rate**
1G	1979 – 1991	800 MHz and 1900 MHz	Nil
2G	1991 onwards	450 MHz, 900 MHz and 1800 MHz	50 kbps (max)
3G	1998 onwards	2100 MHz	2 Mbps (max)
4G	2009 onwards	600 MHz to 2.4 GHz	500 Mbps (max)
5G	2021 (expected)	Sub 6 GHz and mm wave	20 Gbps (max)

Table 1.1: Summary of the cellular network generation

Above table. 1.1 shows changes of the generations in wireless systems which have been developed in terms of various important user oriented parameters such as date rate, mobility, spectral efficiency and coverage. There is leap and bound improvement in these features observed when any new generation has been evolved. Fig. 1.1 depicts pictorial view of changes in form of data rate of various cellular generations and other wireless communication standards [6]. It has also shown utilisation of spectrum by between licensed and unlicensed spectrum changes of the generation.

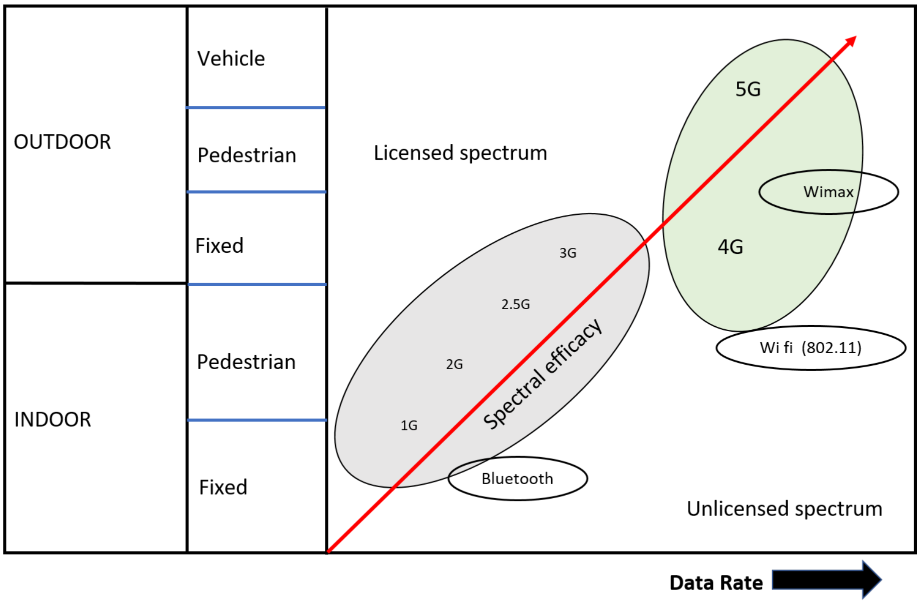

Figure 1.1: Growth patterns of the wireless and mobile communication.

1.2 5G Communication Overview

The innovation in cellular mobile technology made it conceivable to communicate voice over microwaves, beating the mobility restrictions of wired phones. All these wireless communication utilize electromagnetic spectrum. The spectrum is restricted and regulated as various administrations, and share it to meet their particular need and application. With fast growth of telecommunication their wide usage in business, individual use, and diversion, the interests for spectrum have expanded throughout the years in accordance with the huge demand of high data traffic and data rate. Even 4G is not able to cope with the demand of traffic necessities beyond a level, regardless of whether the accessible spectrum is completely used. There are two different ways to satisfy the need of the hour. It is either by exploiting unharnessed frequency spectrum or by utilizing the spectrum resourcefully. 5G technology is able to accomplish both of these way efficiently [7].

It is relatively easy to draw on the strengths of this continuum, but the technical challenge is to solve its limitations. At the same time, 5G empowering technology will resolve the gaps in the current network infrastructure to unleash a whole new range of awaited applications, and usage cases with promising speed, capacity and efficient bandwidth for both businesses and customers, 5G networks will meet connectivity needs across sectors, businesses, and consumers [8].

5G mobile communication technology is being planned to cope the requirements of integrated services such as higher date rate, high reliability, low latency, and enormous connectivity. It was considered keeping view of the excessive growth of mobile traffic and exponentially increase in new user based services [9].

The key development of the 5G communication is enumerated below which depicts the development summery in respect of the various country initiative undertaken and its future prospects. Table 1.2 presents a brief summary of development process in 5G technology [10].

In order to cope up with requirement proposed for 5G communication, the infrastructure of the 4G is very negligible. The detailed comparison of present 4G and proposed 5G is depicted in the figure 1.2 below.

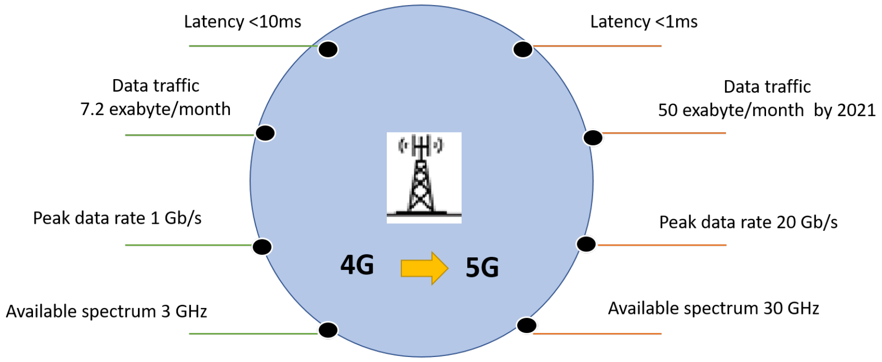

Figure 1.2: Evolution of 5G technology as compared to 4G.

ITU-R in 2015 has released envisioned usage scenarios for the realization of the emerging applications for the cellular communications in 2020 and beyond [11]. Further, 5G network was envisaged with minimum requirement of the ever increasing demand of user and devices. A brief of the requirements based on different radio parameters for IMT-2020 5G technology are listed in table. 1.3 below.

Year	**Development Summary**
2011	Consideration of mm-wave as a new spectrum for 5G cellular technology
2012	United States and Japan steered the research is for 5G technology
2013	Samsung in South Korea proclaims progress of the 5G cellular technology Nippon Telegraph and Telephone (Japan) leads 5G research India and Israel initiates a program Huawei (China) steers research on 5G network
2014	Japan launches its 5G Mobile Forum. South Korea announces strategy for 5G mobile network. European Commission starts 5G research.
2015	IMT-2020 of ITU-R framework roll out ITU-NR lays down the requirements and development step of 5G cellular technology. Huawei demonstrates first 5G test bed.
2016	United States freed a huge bandwidth in high-band spectrum for 5G. China begin conducting technical trials. Nokia, NTT Docomo, and Ericsson leads in 5G research European Union approves its action plan for launching of 5G.
2017	5G trials has been completed by 77 operators in 49 countries. 3GPP approves Non-Stand Alone (NSA) mode of 5G NR specifications.
2018	5G network is launched by a number of countries in some locations. Qatar launches its 5G network. South Korea rolls out a 5G on a trial basis at the 2018 Winter Olympics. 3GPP admires, approves the standard for 5G technology
2019	South Korea begin 5G network deployment commercially Department of Telecom, India has set up research development centre at IIT Chennai for 5G ecosystem. Philippines has rolled out network for 5G communication which includes data plans.
2020	5G services trials were launched in many major cities MTS has started test zones in Minsk with Huawei and Cisco for 5G network. Huawei has agreed under memorandum to supply the equipment for 5G network. ZTE has announced to launch in Belarus for 5G network. Reliance Jio has announce regarding fully owned developed 5G expertise in India.
2021	Most of the mobile and network services around 5G would be kick off. 540 million units of Smartphone shipments are estimated

Table 1.2: Key developments in 5G technology

Radio Parameter	**5G requirement**
Peak data rate (download)	20 Gbit/s
Peak data rate (upload)	10 Gbit/s
Downlink data rate (user experienced)	100 Mbit/s
Uplink data rate (user experienced)	50 Mbit/s
Latency time (packet travel time by Radio network)	4 ms
Mobility (Maximum speed for hand over)	500 km/h
Mobile density (Total number of mobile connection/sq.km)	1 million
Peak spectrum efficiency (downlink)	30 bit/s/Hz
Peak spectrum efficiency (downlink)	15 bit/s/Hz

Table 1.3: Requirements of 5G based on different radio parameters

1.3 Spectrum Requirements

All mobile technology have used microwaves frequency of the electromagnetic spectrum to provide access. The electromagnetic spectrum is expanding from low frequency to gamma ray radiation. In between these two extremes lies the radio frequency, microwaves, mm waves, Infra-red, visible, UV and X ray radiation. Radio waves find its usage in most of the wireless communication applications. Microwaves, utilized by many versatile applications, involve a frequency ranging from 1 GHz to 300 GHz. The coverage in the low frequency waves is high as they can propagate a long distance and they can penetrate buildings. On the other side, higher wave frequency carries more data [12].

The introduction of 5G technology rely on multiple bands in the spectrum to optimise the coverage and increased data rate by exploiting the advantages of higher frequency bands. These include the mid-band, ranging from 1 GHz to 6 GHz, and high-band ranging from 24 GHz to 300 GHz. These two regions of the spectrum are commonly termed as sub 6 GHz and mm-wave in 5G terminology. In urban and suburban scenarios, the lower frequency region would enable broad coverage and penetration inside buildings, whereas the high frequency in mm-wave region, comprising of huge bandwidth and has large spectrum availability [13]. It would fulfil the demand of bandwidth, latency and high-speed broadband applications in urban areas.

Low-band (below 1 GHz) and mid-band (1 GHz to 3 GHz) frequency spectrum are currently utilised for 2G , 3G and 4G telephony, but the mm-wave band spectrum is intended to meet the strict specifications of 5G standards. To boost the efficiency and enhancing the capacity of the network, 5G has been aimed to leverage the output characteristics of each band. Therefore, the low frequency spectrum would consist of the 5G coverage layer, and the high frequency spectrum of mm-wave band would be the layer that is intended for high data rates, and capacity [14]. 5G technology is a promising technology, which has been invented for diverse spectrum from low frequency (below 1 GHz), medium frequencies (between 1 GHz to 6 GHz) and high frequencies (in mm wave range). This will provide soft handover from existing spectrum to new spectrum and that to promising 5G specifications.

TRAI (Telecom Regularity Authority of India), under ministry of communication, Government of on the recommendation and proposals of 3GPP has taken initiative to identify available spectrum for 5G. In mid band (1 GHz to 6 GHz), n77 band has been identified which ranges from 3.3 GHz to 4.2 GHz apart from existing mobile spectrum while catering demand of defense and space requirement. In mm Wave range, n257 (26.5 to 29.5 GHz) and n260 (37GHz to 40 GHz) have been found suitable in the initial phase for launching 5G services keeping view of high band width demand of in device to device communication [15].

Previously, because of the high propagation losses and blocking by building materials and vegetation, but also by the human body, the use of frequency bands well above 6 GHz was not considered suitable for mobile communications. Although, these challenges impose restrictions on mm-wave deployments, new antenna technologies allow a range of deployment scenarios to be considered together with a good sense of channel characteristics and signal propagation. The high losses and blocking of penetration mean that mm-wave deployments can cover outdoor or indoor areas, but do not have indoor connectivity outdoors.

Therefore, the mm-wave cell sizes would be smaller and higher in density. It can also be anticipated that mm-wave will co-exist with 5 G networks below 6 GHz as well as 4 G LTE in a close integration. In order to maintain efficiency and coverage, quick adaptation to changing channel conditions will allow switching within and across cells [16].

The roll-out of 5G cellular mobile services would be contingent on regulatory bodies and policymakers to provide affordable access to the users with the allocated spectrum, while addressing the technological challenges in harnessing electromagnetic spectrum. There are several bands of spectrum under consideration at present. However, for global availability, 5G would require a harmonised spectrum. The 3GPP, the body responsible for regulation and supervision, endorses the 3 GHz – 6 GHz, 24 GHz - 40 GHz, and 66 GHz -71 GHz of bands of spectrum for the 5G technology [17].

5G primarily relies on mm-wave band, whose frequencies lies in between 24 GHz to 300 GHz of spectrum that were previously considered to be unsuitable for mobile communications. This band was not historically considered because the waves neither travel far nor have penetration property. Atmospheric characteristics, in the form of rain, vapour, moisture and fog also contributed to signal attenuation in this band. This issue is addressed by small cells, which are an important part of 5G rollout [18].

5G will accommodate a greater number of mobile units in a given cell coverage area, in addition to increased speed and mobility, which may be in the order of 1 million devices per sq. km. a pictorial representation is shown in Fig. 1.3.

Governments bodies of a country or region work with the ITU to assign specific frequency to a particular service on a regional or global premise. The international body to administer it is Radio regulation group of International Telecommunication Union (ITU-R). The Fig. depicts that 5G is anticipated to introduce an increase of critical essential features of the network. These features includes peak data rate, energy efficiency, area traffic capacity, spectrum efficiency, connection density and reduced latency.

The laid a framework for the utilization of the frequency bands of the spectrum. Moreover,

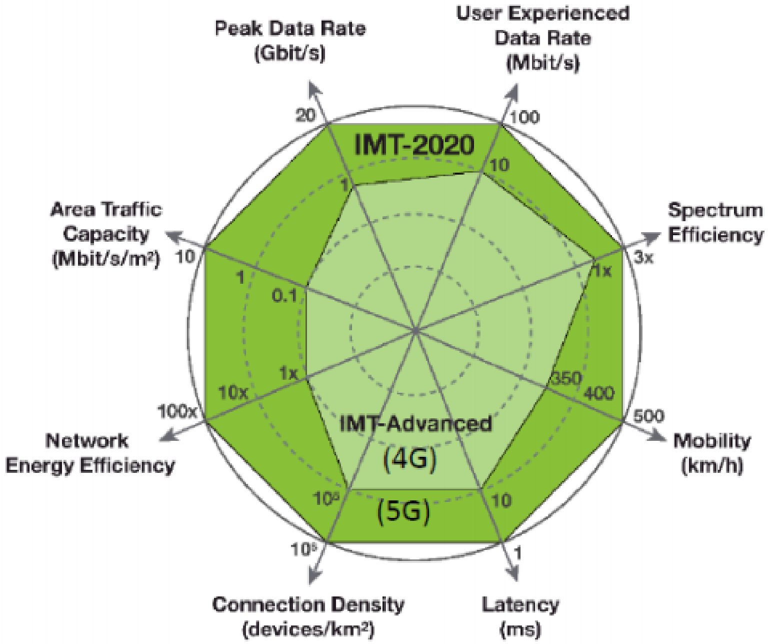

Figure 1.3: Specification of 5G technology [19]

spectrum could be administer either through a license spectrum allocation or unlicensed one, depending upon the characteristics and applications [20].

1.4 Antenna

Radio wave's magic and mystery have been captured imaginations from William Crooke's earliest speculations to the present day. The beauty of wave transmission in wireless media is marvel in the world of ubiquitous and instant broadcast communications. In the voices, images, data, and information conveying vibrations quiver all around us. The magic of radio pushes these signals out of the air and recovers the original one. The Antenna is the wand answerable for this wizardry. A radio wireless device is made possible by an antenna [21].

James Clarke Maxwell first laid out his remarkable equations describing the behavior of the electrical and magnetic fields in 1865. The journey from the Maxwell equation to understand electromagnetic radiation and radio waves took a long 20 years and many debates. The existence of electromagnetism resolved in 1884 with the Henrich Hertz experiment and its demonstration. Hertz led the way as the first to generate radio waves and to subject them to scientific scrutiny.

A large number of innovators such as Nikola Tesla, Carl Barun, Alexander Popov, and Reginald Fessenden contributed key elements to radio technology. The other leading pioneers are Oliver Lodge, J. C. Bose, and Guglielmo Marconi. Bose performed pioneering work in millimeter wave systems and invented horn antenna. But it was Marconi's remarkable work that opened the path of radio communication. Marconi first marketed radio as a means of long-range communication. The fundamental works of these great ones open the antenna technology gateway, and it requires decades of technical development to fully realize the vision of Crookes.

The boundaries of radio science are rising past high-frequency range beyond speech and a new generation of antenna design is emerging to tackle the difficulty of broadband creation. As frequencies used in radio spectrum tens to increase, it leads to a growth in the broadband antenna.Nevertheless, not only frequencies are going high, but bandwidths also became wide. Edwin Howard Armstrong's discovery of Frequency Modulation in 1933 demands twenty times more bandwidth than Amplitude Modulation's first radio broadcast. The advent and rise of television also led to a spur popularity for antennas, which can support a larger bandwidths. Improvement in radio electronics led to higher and higher frequencies and fuelled demand for broadband antennas [22].

FM is a gateway to the transmission of RF-conveyed digital information. The Global System for Mobiles (GSM) group was founded in 1982 and laid the groundwork for modern wireless mobile networks. In the early 19th century, the presentation of the L band digital radio and the publication of the first GSM specification were the primary events in the history of wireless communication. The first GSM call was made in Finland in 1991, and the IEEE standard for WiFi was established six years later. The Bluetooth Special Interest Group was formed in year 2000 with the subsequent launch first Bluetooth device. The science of wireless communication is now advancing rapidly, allowing humanity to communicate easily.

In addition to GSM, CDMA and UMTS, wireless technology provides a massive appeal for advanced voice and data services. Deschamps introduces the idea of microstrip antenna and it was the work of Munson that leads to its first reality. Microstrip antenna has gained tremendous usage with its many features and revolutionise its importance in wireless communication. Moving further in response to advances in radio technology has led to the development of the Super High frequency antenna. A time line of antenna and wireless communication is presented in table. 1.4.

Year	Developments
1865	Maxwell predicts the electromagnetic wave propagation.
1887	Heinrich Hertz showed the existence of electromagnetic waves
1876	Bell developed telephone
1895	J.C. Bose demonstrates 6 mm wavelength transmission.
1901	Marconi transmits first radio signals
1906	Fessenden initiate First Radio Broadcasting.
1914	AM radio broadcasting implemented
1924	Yagi developed directive short wave antenna.
1929	Marconi set up 600 MHz radio link in Italy.
1933	Armstrong developed FM technique.
1953	Deschamps gives an idea of Microstrip printed antenna
1968	First mobile cellular telephony starts
1972	Munson introduces Microstrip patch antenna
1974	Howells introduces circular patch antenna
1991	Digital Cellular service as GSM
2000	3GPP formed
2010	4G mobile communication
2020	5G mobile communication

Table 1.4: Wireless communication and Antenna development timeline

1.5 Performance Parameters of Antenna

Antennas are the backbone of wireless Antennas validate a reciprocity property, which means that it maintains the same features as transmitting as well as in receiving.

- **Bandwidth:** The bandwidth is the operating range of frequencies (lower frequency to higher frequency) over which the antenna radiate efficiently. correctly. This is also the ranges of frequencies, in which the antenna exhibit a reflection coefficient of less than -10 dB or a VSWR of less than 2. All the different class of antennas have different operating bandwidth and also they have limitation of operating bandwidth. The unit of bandwidth is Hz. The bandwidth of a wide band antenna in the microwave zone is usually around 500 MHz or 0.5 GHz.

- **Voltage Standing Wave Ratio(VSWR):** VSWR is a measure of how efficiently the energy from a source is transmitted through an antenna for the radiation. The source and antenna are interfaced with feedline. For an efficient transfer, and subsequently radiation, of energy, the impedance of the source, feedline and the antenna must be perfectly matched or balanced.

  In real systems, any mismatch in the impedance, at the interface, could lease of the reflection of some energy back to the source. This results a standing voltage over the line, and this cause destructive interference. As a result there is up and down of the voltage over time at various path along the line. VSWR is a measure of variation of these voltage, and given as the ratio of the high to low voltage along the transmission path. VSWR is very much related to reflection coefficient or S parameter.

- **Reflection Coefficient:** The reflection coefficient is additional way of conveying the impedance mismatch between the interfaces at source, line and the antenna. The bandwidth of the antenna is easily calculated using the plot of this parameter. Reflection coefficient compares the power reflected to the power fed.

- **Return Loss:** An antenna's Return Loss is a parameter that indicates the quantity proportion of radio waves arriving at the antenna input that is prohibited to those that are accepted. It is measured usually as logarithmic ratio in dB.
  There is a close mathematical relationship between VSWR, reflection coefficient and return loss [23].

- **Gain:** Gain of an antenna is the proportion of the intensity of the radiation provided by the antenna in a given direction to the radiation intensity that would be achieved if a similar power is dissipated the antenna in all direction uniformly i.e. isotopically.

  Essentially, gain of an antenna considers the directivity also as a measure of its execution. The intensity acknowledged by the antenna when transmitted isotropically (that implies every which way), is taken as reference. In contrast to directivity, antenna gain considers the losses during radiation, and hence taken the magnitude of intensity as its measurement.

Gain is measured in dB. The radiation from the isotropic is in all direction with equal magnitude of power. In practice, real isotropic antenna has found no existence, but it provides an insight comparison with the practical antenna radiation property. The gain is measured by equating the test antenna with a standard calibrated antenna. An antenna doesn't generate power, so the total power radiated of any antenna is equal to that of an isotropic antenna, but the distribution in directions are not uniform.

- **Directivity:** The ability of focusing the radiation energy in a particular direction is termed as the Directivity of the antenna. For a receiving antenna this term defines the ability of the antenna to collect the energy from a particular more than the other direction. So, the directivity helps in radiating or collecting the energy in a specified direction.

- **Radiation Pattern:** The antenna can emit radiation distributed in space in a certain manner when a signal is fed into an antenna. A radiation pattern is considered as a graphical representation of the distribution of radiated power in space. The radiation or antenna pattern defines the relative intensity, at a constant wavelength, of the radiated field in different directions from the antenna. The radiation pattern is also a pattern of reception, as it also defines the antenna's receiving properties. The radiation pattern is three-dimensional, but the measured radiation patterns are typically in the horizontal or vertical planes, a two-dimensional slice of the three-dimensional pattern. In either a rectangular or a polar shape, these pattern measurements are presented.

  The radiation pattern is not the same as the pattern at large distances in the area close to the antenna. The term near-field applies to the field pattern that occurs close to the antenna, while at wide distances the term far-field refers to the field pattern. The far-field is often called the field of radiation, which is what is of concern most frequently.

1.6 Microstrip Antenna

In a number of ways, an antenna can be classified [23]. The simple antenna structure is the wire antenna. This simple structure is considered to be the oldest one and cheapest too. It is also the multi purpose and wide used antenna for many applications. In the same category of wire antenna comes the loop antenna and helix antenna. The shape of loop is of any geometrical structure, whereas helix is forms from a large section of wire.

Other than the wire, solid conductor having two-dimensional surface, of finite dimension, are used to design the antenna. The structure formed is called aperture antenna. In this category horn antenna and disc antenna falls. The shape of the horn antenna is determined by the cross section of the waveguide, a hollow metallic tube of rectangular or circular shaped used to carry the radio waves in closed structure. Disc antenna is also referred as parabolic disc antenna and they are used mainly in long distance communication. The disc collects the radio waves and directs towards the feedline.

One of the new developments for antennas and electromagnetic applications is the introduction of the microstrip antenna. Owing to its simplicity and compatibility with printed circuit technology, it is widely used today in the wireless communications system. In the 1950s, microstrip geometries were originally envisaged and the microstrip antenna concept was first suggested by Deschamps [24]. Munson [25] and Howell [26] were credited for the first practical antenna structure of this class.

Throughout the broad field of microwave antennas, comprehensive research and development of microstrip antennas, supported with development in fabrication technologies, kicked off a rapid and versatile research keeping in mind the diversified wireless applications. The usefulness of the microwave range plays an important role in the modern wireless systems, and it spurs the usage of microstrip antenna primly in super high frequency and extremely high frequency that covers the microwave and mm wave region [27].

Some of the notable characteristics of microstrip antenna includes its low profile structure, adapted to planer surface and easy integration. The other noticeable features includes light eight, low volume and ease in fabrication. Though low bandwidth and low gain are its demerits.

1.7 Structure of Microstrip Antenna

Three layers form the fundamental structure of a microstrip antenna. The upper metallic layer purpose is to radiate and collect radio energy . The metallic layer referred to as the ground plane is the lower layer. Both these layers are very thin, and typically made from copper or gold. The third layer is a finite height substrate of dielectric material [30]. During the method of fabrication of the microstrip antenna, the metallic layers are engraved over the substrate. Microwave and mm wave regions are the preferred choice of operating frequencies for this type of antenna. The metallic layers of this antenna are of any form, but rectangular shape is the most common shape. Other ideal shapes are circular, square or normal geometric shapes, as per the output requirements. There is no variation in the radiation characteristics of the microstrip antenna, irrespective of the geometric form [31]. As a bulky substrate adds more surface waves and reduces the radiation power, the height (thickness) of the substrate is not held high. The microstrip antenna radiation occurs due to the fringing fields produced between the edges of two metallic layers (upper radiating and lower ground) (upper radiating and lower ground). The radiating layer offer low resistivity, high conductivity, resistance to rusting, and ease in soldering. A layout of a planner microstrip antenna, along with its different constituents, is shown in figure 1.4

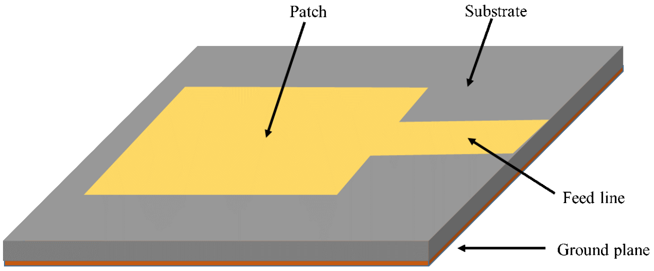

Figure 1.4: Structure of a Microstrip antenna with its basic constituents

A slot is a narrow two-dimensional configuration of a planer engraved on one side of the substrate in the metallization. In microstrip antenna, it is well suited due to its planer geometry. In nature, the effect of the slot is capacitive. Its key benefit is that it matches the impedance very well if cut at the right place with right dimension. Hence, it is necessary to research the location of the slot on the patch because if it is not made at the appropriate position, an antenna can suffer from undesired mode such as excitation in parallel plate mode and its output tends to degrade [32]. A symmetrical microstrip antenna with slot is shown in Fig. 1.5

To achieve the perfect configuration, researchers are currently designing the antenna at well fitted in device operating at very high frequency [33]. Looking into the features and property of the microstrip antenna, there is a trade-off between an antenna's size, bandwidth and gain and the threshold is as per the application requirement [34].

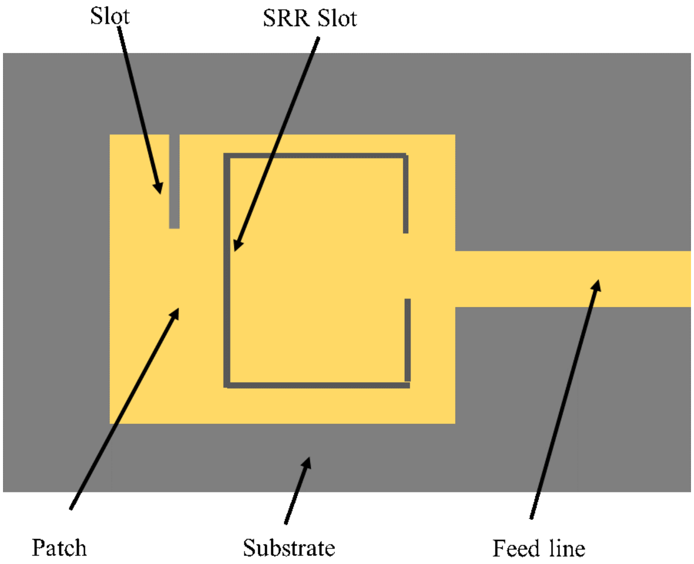

Figure 1.5: Structure of a Microstrip antenna with slot structure on the patch

1.8 Common Methods of Feed for Microstrip Antenna

The feed is used to direct the energy from the source to antenna. It provides an interfacing between the the two layer. The energy travels along the antenna structure and radiates into free pace. there are many methods of providing the fedding, and they are quite . different from each other in terms of construction and usefulness each of these methods have their pros and cons [35].

The feeding strategies are divided into two groups, one contacting and one non-contacting. The contacting method is usually called the direct method, while the non-contacting method is called the indirect method. In the former class of feeding methods , energy is supplied directly to the radiating layer of the antenna , whereas in the latter type of feeding technique, energy is transferred by some coupling mechanism. Microstrip feedline and co-axial feed falls under contacting types of feeding methods. In the latter case comes the Coplanar waveguide feed, aperture coupling feed and proximity coupled feed [36].

The efficiency parameter of the antenna is affected differently by all of these feeding methods. Gain, directivity, bandwidth, impedance and radiation are the parameters that have a profound impact on the choice of these methods [37]. For optimal impedance matching and transmission of full power from the source to the antenna, the impedance of the two should be perfectly matched. Salient features of these feeding methods are mentioned in table. 1.5.

Microstrip Line Feed is the most convenient one and this feeding technique is chosen in the present work. This feeding method is widely used, especially in microstrip antenna, as it provides ease of fabrication, good impedance matching and as well as simplicity in analysis of the antenna.

In this method of feeding, a conducting strip connects the source and the antenna directly. The width of the strip, known as microstrip feedline, is always smaller than the width of the radiating surface, commonly termed as patch, of the antenna. The advantage of this type of feeding method is that beside the planer structure it provides ease in fabrication, as the feedline can be printed over the substrate at the same time as the radiating layer [38]. This advantage leads to the design of large arrays by using edge-fed radiating elements. Radiation from the feedline, as leakage of power, is the disadvantage provided by this method.

Feeding Method	**Features**
Coaxial Feed	It is easier in matching It possesses low spurious radiation It introduces large inductance for thick substrate Soldering is required at the junction.
Microstrip Feed	It is easy in fabrication. The nature is monolithic It is easy to match by controlling the position of feed. For thick substrate, this lead to spurious radiation from feed line for significant width of line.
Aperture Coupled Feed	There is no direct contact between feed and patch. It leads to avoid large probe reactance It requires multilayer fabrication, which is not easy. It produces high back lobe radiation
Proximity coupled Feed	It provides wider bandwidth. It gives a flexibility of the choice of two substrate with different dielectric values. There is difficulty in the fabrication process, as multiple layers need to be properly aligned.
Coplanar waveguide feed	This feed is printed along the same axis as the radiating layer of the antenna It offers high bandwidth. It suffers high radiation from the feedline element, which accounts for the poor front to back ratio.

Table 1.5: Features of different feeding methods

1.9 5G Communication with Microstrip Antenna

The Microstrip antenna has proven an outstanding choice in majority of applications as compared to its conventional microwave antenna. Its noticeable advantage makes it a perfect choice for its usage from a wide range of wireless operation ranging from hundreds of MHz to hundreds of GHz of frequency.

Over the past two decades, antenna technology has witnessed remarkable achievements. The specifications of the microstrip antenna depend on the composition of the substrate and the output of the antenna mostly depends on that material's dielectric constant and loss tangent. It is expected that the introduction of new mobile 5G standards and the implementation of mm-wave spectrum would be ground breaking. As the futuristic communication is heading from 4G LTE to 5G technology, mm-wave bands would be able to provide enhanced performance, enhanced coverage, and greater integration through various wireless technologies.

With this, the Mobile Communication Development System has evolved rapidly. There was a considerable emphasis and research interest from the era of GSM to WCDMA and then it traces its path to LTE-A and 5G cellular. Microstrip antennas are one of the definitive options to endorse compact implementation of wireless networking terminals and have been widely implemented in various applications, ranging from Mobile Communication (GSM, WCDMA, LTE, LTE-A) to Global Positioning System (GPS) as well as Wireless Local Area Network (WLAN) [39].

Microstrip patch antenna has shown the remarkable results while considering miniaturization and coping wide range of the frequencies.

1.10 Motivation and Objectives of this Research

The rapid increasing requirement for the bandwidth and available spectrum has encouraged to explore more available frequency band and to overcome the limitation of the specific bands, since there is global bandwidth limitation in lower microwave bands lower than 3 GHz.

With mobile traffic explosively rising and users' appetite for new technologies and apps increasing rapidly, 5G mobile networks are now being built to meet the requirements of these services. Use of underutilized Sub 6 GHz band and mmWave will meet the requirements as per the 5G networks. Therefore, utilized spectrum has identified for enabling the 5G communication. Recently the Sub 6 GHz band and millimeter wave band are validated bands for 5G communication by the international regulating agencies also. In addition, millimetre wave is a key technical enabler for the realization of the futuristic communication in the form of 5G technology.

With taking the inputs from the requirement added with initial literature review, research gaps are identified, and it leads to the formulation of these three objectives of the thesis work:

1. Design of multi-resonance antenna for Microwave and Millimeter wave communication system.
2. Fabrication and experimental realization of designed antenna for future communication system.
3. Characterization and verification of the designed antenna.

1.11 Organization of this Thesis

This research work has been presented in five chapters. Chapter-wise summary is as follows:

Chapter 1: The first chapter presents the introduction of the 5G communication, frequency spectrum for this cellular mobile technology and journey of its developments. this chapter also includes a brief on historical advancement in antennas,and added with microstrip antenna. the advantages, limitations, structure, performance parameters, and brief description of feeding methods are also presented. A summary of frequency spectrum availability is also discussed. This chapter depicts about edge of Microstrip antenna for 5G communication keeping view of the design parameters. This chapter also comprises with the motivation, objectives and brief description of the thesis content.

Chapter 2: The second chapter deals with an elaborative literature review done in the field of 5G communication and its requisite specifications for the transmission and reception of the RF energy, various proposed 5G spectrum band by international agencies and national regulatory bodies, characterization of the mm wave and sub 6 GHz antenna for 5G technology, various techniques and optimization schemes used particularly for the enhancement of impedance bandwidth, gain and improvements of performance, etc. The detailed literature review is asserted to achieve the multiple resonance in the desired bands.

Chapter 3: In the third chapter, a multi resonance in sub 6 GHz band antenna design is presented. The proposed antenna has three bands as per DoT specification, and it finds its usage in LTE and 5G networks. The antenna has been designed with inverted planer slot and split slot techniques to obtained the desired results compatible for 5G. This design was undertaken keeping view of the various available band for proposed communication in single antenna so that various application may be incorporated in single design. The results of simulated and fabricated are discussed, and the measured results are also compared with existing published literature.

Chapter 4: This chapter includes a dual band mmWave antenna. This antenna design depicts the dual resonance in mmWave range suitable for proposed 5G communication. The antenna comprises with two concentric split rectangular rings with guided slot structure on the feedline. The antenna is very precise in its operating frequency with adequate bandwidth requisite for futuristic communication technologies. The proposed antenna is fabricated and tested. The performance parameter of the simulated and fabricated results are discussed. The measured results are also compared with existing published literature.

Chapter 5: The conclusions drawn from the investigations done in the past and the accomplishment of the proposed antenna is discoursed. The scope for future work are mentioned at last.

1.12 Chapter Summary

This chapter presents the futuristic communication focusing on the aspects of 5G technology. It also explains the importance, development,need and types of antennas, with more emphasis on the microstrip antenna. It depicts advantages, limitations, and applications of microstrip patch antennas, their performance parameters and a summarized their excitation techniques. This chapter also comprises the motivation, objectives, and a brief description of the thesis content.

Chapter 2

LITERATURE REVIEW

2.1 Literature Review on the Design of sub 6 GHz Antenna

In 2014, Kaur [40] presented a dual-band microstrip antenna design. In the work proposed by the researcher, the radiating structure is a pair of inverted L-shape and the ground structure is a cross-shaped one. The substrate used in the design work is FR4, having thickness of 1.6 mm and dielectric constant of 4.4. The design antenna is producing two separate operating bands from 3.34 GHz to 3.54 GHz and 4.90 GHz to 6.26 GHz. The impedance bandwidths are adequate to show good result in the prescribed range of frequencies. The researcher claimed the design to be well applicable for local wireless network and microwave access worldwide. Beside this the range from 5.650 GHz to 5.670 GHz and 5.830 GHz to 5.850 GHz is fit for amateur satellite applications, and 5.9 GHz for providing wireless link in the vehicle technology. The design antenna was simulated using various substrate materials. The antenna was fabricated with optimised parameters. The results were validate with some measurements. The process of design is presented, and steps are discussed in order to achieve the required performance.

In 2015, Munir et al.[41] proposed a dual band antenna. They also incorporated an array of split ring resonator structure. The use of this structure on the single band microstrip antenna produces dual-band antenna. The proposed antenna is intended to work on two frequency bands are applicable in the area of wireless local area network and global positioning system applications, It is composed of 3 copper conductor layers that flank 2 layers of dielectric substrate FR4 Epoxy. The size of the antenna is 1.6 m and 72 mm x 51 mm, respectively with FR4 substrate. It also contains three copper flank layer. The measurement results shows the dual band at 1.52 GHz and 2.47 GHz of frequency. The conventional single band microstrip resonates at a 1.555 GHz of frequency in their design.

N. Daud et al.[42] in 2017 presented a dual band antenna design for mm wave operation. In terms of reflection coefficient, the performance of this dual band antenna is analysed for frequencies 24.25 GHz and 38 GHz . The dimension of the radiating patch is 4.9 mm x 7.6 mm. The thin substrate used by the researcher in their work is RT Duroid of dielectric constant 2.2, and the height is only 0.127 mm. The proposed antenna at the desired frequencies realized a peak gain of 5.5 dB at 24.25 GHz and 4.5 dB at 38 GHz of frequency respectively. The simulation works were carried by using CST Microwave Studio software, and the researcher claimed the antenna to be appropriate to apply the proposed design in the 5G wireless system.

In 2017, Kumar et al.[43] explored an incorporated defected ground structure design on the microstrip array structure. Their work was to achieve enhanced polarisation. For rectangular arrays, defective ground structure with flexible shapes were conceived and constructed. This enhances the design capacity by that by 50 percent the etched out area. The array structure is a 2 by 2 element in the lower frequency band of the microwave region and experimentally showed a good isolation between the co polarisation and cross polarisation. The researcher cited the benefit of one defective ground structure in the case of dense array element design, where the inter-element spacing is minimal.

In 2017, Houti et al.[44] proposed and experimentally investigated an equilateral-triangular antenna under sub6 GHz of frequency. The antenna is fed with coplanar waveguide feeding method and involves an L shape parasite design structure. Both the experimental and simulated results are in accordance with each other. It get a three specific bands with good isolation and constant variation of gain. The three resonating bands are in the range of 2.33 GHz to 2.83 GHz of frequency, 3.34 GHz to 3.58 GHz of frequency, and 5.5 GHz to 5.9 GHz of frequency. A strong omnidirectional radiation has also been achieved in the H-plane. The operating bands finds its usage in WiMax and wireless network also.

W Ali et al.[45] in 2017 introduced a design structure of triple-band microstrip antenna. The researchers utilised multi-unit cell concept in the design. The design includes one rectangular split ring resonator element and two circular split ring structure. The three bands obtained are 2.45 GHz, 3.56 GHz and 5.6 GHz of frequency. The lower band is obtained by the rectangular structure. The antenna is also meant to find its usage in wireless network system. The operating bands as covered by the triple resonances showed reasonably improved efficiency by the proposed antenna. A comprehensive parametric analysis of the positioning of the split slot structure implemented and the location of the unit cells for improved efficiency is also shown by the researchers. A good continuity between simulation and measurement demonstrates the potential of the design as purposeful multi-antenna.

In 2017, K. Ishfaq et al.[46] proposed that 5G, the fifth wireless communications generation, focuses on multi band frequency regions. These includes frequency around 6 GHz, 10 GHz in X-band, 15 GHz in Ku band of microwave region and in the mm wave region the frequency are 28 GHz and 38 GHz. To cover these distant frequency bands, the industry demands multiband antennas, which is a far more demanding task. They proposed a design consisting of a planar inverted-F antenna based multiband split-ring resonator for 5G applications in their work. The design of the patch antenna includes a combination of planer inverted F slot, and inverted-L unit element, a parasitic rectangular unit, and a split ring slot resonator element. The plain F slot design operates at 6 GHz of frequency. The resonance at 8 GHz and 10 GHz is made possible by the inclusion of rectangular split ring structure. Resonance at 15 GHz is possible due to the addition of a rectangular shaped parasitic part. Inverted-L shaped structure helps in improving the impedance bandwidth.

Ngobese et al.[47] in 2018 examined the design parameters of a wide band wide versatile antenna for working under sub 6-GHz of frequency. The proposed occupies the mid-band spectrum ranging resonating at 5.216 GHz. The gain and directivity achieved are 9 dB and 12.8 dB respectively. This high value of these two parameters are achieve dby uisng array of antenna element. The simulation is acrrie din CST software and in addition, the measurements of the fabricated prototype support the simulated performance. The antenna also finds its prime usage in WLAN application.

Nelaturi et al.[48] in 2018 proposed a compact microstrip antenna in lower Microwave region of spectrum. The base design antenna is proposed to operate at 3.3 GHz of frequency and furthermore using split ring resonator structure, 2.4 GHz of the resonating frequency is achieved. The design antenna is usage in WiMAX bands and wireless fidelity bands. Authors cited the reason for the low frequency band (2.4 GHz) to be the left-handed nature of the complementary split ring resonator slot structure. The bandwidth and return loss is increased by carving fractal slot at the edge of the patch and this also improve the axial ratio on the upper band. The simulation work was done by using HFSS software and the a comparison is presented with the measured data. The researchers claims that using the fractal structure , the volume of the antenna is 25 percent less than the existing antenna at 2.4 GHz of frequency.

In 2018, Atik Mahabub et al.[49] presented a multiband patch antenna in sub 6 GHz of frequency. The three resonating frequency are at 2.4 GHz, 7.8 GHz and 33.5 GHz of frequency. The tri bands usage lie in the application in the area of wireless fidelity, WiMax and 5G wireless network. For each aforementioned operating frequency of systems , a good directional radiation, high gain and good VSWR are obtained. This simulated antenna designed by the researcher is for multiband applications that can't only be powerful for Wi-Fi and WiMAX, but also for 5G too.

John Doroshewitz et al.[50] in 2019, proposed a three-band antenna. They used a distributed beamforming at 1.88 GHz and using a high precision sparse, two-tone waveform operating near 9.5 GHz and 10.5 GHz of frequency is achieved. A slotted patch antenna surrounded by a larger patch antenna supporting the 1.88 GHz array signal supports the two-tone waveform. The antennas are concentrically designed to ensure that they are closely aligned with the phase centres of the ranging antenna and the coherent action antenna. The simulated and calculated output indicates a phase centre displacement of approximately /10 relative to the coherent signal of operation, while preserving S parameter at each band below -10 dB.

In 2019, Chatterjee et al.[51] discussed a novel approach to miniaturising a simple rectangular patch. The Microstrip feed line was used at 2.45 GHz to stimulate the structure. The design has been optimised by inserting a circular slots on the surface of the radiating patch. The effects of different radius slots on the reflection coefficient and overall size are thoroughly studied. The improvement in the impedance matching and gain was done with the help of a 3x3 array. The design of the array is accomplished by split ring resonator structure. The work is simulated one and the simulation is carried on CST platform.

In 2019, Jacob et al.[52] presented a microstrip patch antennas citing its usage in many fields due to their requirements such as compact size, less weight, less cost. The researchers design a miniaturized 2.4 GHz frequency patch antenna. The size of an ordinary patch antenna intended for this work was a square structure of dimension 7 cm x 7 cm. To miniaturise the patch antenna, both the split ring resonator and complementary split ring resonator structures were used. They demonstrated this structure as metamaterials, showing an LC resonator circuit action. The researchers showed that there is shift in the frequency response towards the higher frequency side when the size is reduced. In order to compensate for these split ring structure is the ideal solution, showing a patch antenna design with reduced size and optimised frequency response. With this split ring structures, the antenna is miniaturized to 2 cm x 2 cm in dimension.

In 2019, Tang et al.[53] put the design of microstrip antenna as per the Chines frequency specification of 5G technology in sub 6 GHz band. Citing the significance of microstrip patch antennas of the antenna family, the proposed design is a tri band antenna. The frequency range chosen for the design purpose from 2.515 GHz to 2.675 GHz for the first band, 3.4 GHz to 3.6 GHz for the second band and 4.8 GHz to 4.9 GHz for the third band in order to realise 5G wireless communications. The design work includes an alteration in the configuration of the ground plane and using adjustable step-impedance resonator structure. The first also find sits usage in the area of Bluetooth and wireless local networking. The antenna obtained a gain of 2.52 dBi at 2.55 GHz of frequency, 3.04 dBi, at 3.5 GHz of frequency and 4.31 at 4.75 GHz of frequency respectively.

Kamran et al.[54] in 2019 demonstrated an integrated MIMO antenna design. The design structure is for both the 4G communication technology of LTE specification and mm wave band of 5G technology frequency specifications. For LTE, a two-element MIMO structure is proposed and in the usage for 5G technology, four-element MIMO structure was utilised. The proposed design is defective ground plane with circular slot and rectangular slot elements. Rogers RO4350B substrate of height 0.76 mm is used as substrate material in the fabrication process of the design antenna. The total dimension of the substrate is 75 mm x 110 mm. The array design resonates in the frequency region from 5.29 GHz to 6.12 GHz and 26 GHz to 29.5 GHz of frequency. The first region is for LTE operation and second frequency range is 5G mm wave system. The measured gain at the two region of resonating bands are 5.13 dB and 9.53 dB respectively. MIMO performance metrics results in a good efficiency and radiation intensity of the design antenna. The researchers also cited the SAR value of the antenna and it is consistent with international safety requirements.

In 2019, Asnani et al. [55] proposed a compact patch design antenna. The design is consisting of a partial ground plane structure with balanced parasitic elements. The structure also includes a rectangular slot with an I-shaped patch, which helps in increasing the operating bandwidth and the feeding is done with an extended microstrip line. The dimension of the proposed antenna is 15 mm by 20 mm by 1.6 mm. the substrate used in the design is FR4 material whose dielectric constant is 4.3. The design shows a good impedance matching in three bands. The first band is from 2.34 GHz to 2.46 GHz of frequency, the second band is from 4.61 to 5.92 GHz of frequency and the last band is extending from and 9.0 GHz to 9.9 GHz of frequency. The higher frequency bands gave again of 3 dB , whereas the value of gain the middle band is 2.17 dB.

In 2019, Amrit Kaur et al.[56] demonstrated a miniaturised planar inverted F antenna for sub 6 GHz application. The designed antenna is meant for both 4G and 5G mobile applications. The operating range lied from 2.9 GHz to 4.9 GHz of frequency range and it includes all sub- 6 GHz frequency bands worldwide. They cited that the planer inverted F antenna structure is quite basic and trouble-free, and the dimensions are quite small as the size of the patch is 11.3 mm x 8.3 mm. The antenna shows S parameter response of -37.9 dB at a frequency of 3.9 GHz. The researchers claimed that where simplicity is the issue for the 5 G world, their design it seems truly promising. The antenna is 4G-compatible and useful for 5 G wireless technology.

Olawoye et al.[57] in 2020 introduces the concept of a slotted ground plane structure in the antenna design for wireless communications under sub-6 GHz frequency region of the 5G technology. The slot is T shaped slot on the radiating patch of the antenna, and a modified C shape slot in the ground plane structure, thus making it a defective ground structure design. The modified C slot is integrated with special laceration at the upper and lower portion of the slot and helped in increasing the efficiency. The design also includes a reflective plate enabling the radiation in the prime lobe by reducing the side lobe radiation effect. This structure also increased the gain of the overall design antenna. The substrate used in the design work is FR4 and inset feed technique is used for the feeding purpose. The suggested antenna is designed on an epoxy substrate of FR-4 and implements the technique of inset feeding. The size of the antenna is 28.03 x 23.45 x 5.35 mm. The max value of directivity and gain obtained from the simulation work are 7.1 dB and 5.5 dB respectively. The working range of the design antenna lies in between 4.775 GHz to 5.049 GHz of frequency, and it is in the sub-6 GHz 5G communications range.

Kapoor et al.[58] in 2020 suggested an antenna design in the sub 6 GHz of frequency region. The operating frequency chosen by the researchers is in accordance with the frequency proposal for the 5G communication system. The region of frequency bands lie under 6 GHz of frequency band. The proposed compact microstrip design antenna operates from 3.3 GHz to 4.0 GHz. It is also useful for wireless application in C band. The wide bands are achieved by using slotted partial ground techniques, and altering the configuration of the ground plane of the antenna. The achieved gain is 2.5 dB.

2.2 Literature Review on the Design of mmWave Antenna

Tanvi Agrawal et al.[59] in 2015. Showed a design of a multiband microstrip patch antenna was shown by The work is using a complementary split ring resonator structure. In the work, multiple bands are achieved by etching the ground plane by of split ring resonator. It also achieved a miniaturisation of the design microstrip antenna. The results were presented with 2, 4 and 6 inclusions of complementary split ring resonator structure, and analysis work have been compared in this work. They showed that the viability of multiband design is because of the quasistatic resonance possessions of ring resonators.

In 2016, Aliakbari et al.[60] demonstrated a dual band antenna in mm region of spectrum. The resonating frequency of their circularly polarised slotted microstrip antenna are 28 GHz and 38 GHz. The frequency is appropriate for 5G millimetre wave mobile communication. The proposed circularly polarised monolayer antenna is energised by a microstrip feed line method. The feedline is a desirable choice for the implementation in the millimetre wave band. It also compensate the loss of the link as proposed by the researchers. In their simulation work, the effect of dimensions of the slots has been studied and described with a significant effect on the antenna performance. The antenna has been fabricated and measured depicts its usage for the upcoming 5G mobile communications. It also at the same time provide circular polarisation in the two bands.

In the year 2016, Roy et al.[61] presented a simulated design of the 1X6 silicon and Roger RO4003 substratum millimetre wave square patch antenna array design. Their work shows multiple frequency bands in the very high frequency region ranging from 58 GHz to 60 GHz, 65 GHz to 68 GHz, and 72 GHz to 77 GHz. The proposed work is intended for device to device network in 5G cellular networking. Their work claimed to be useful in serving 5G cellular network in reducing latency end to end. The antenna possesses a high gain of 9 dB and is of very high efficiency. At their resonant frequencies, the return loss for certain bands is as low as -35dB and with 9.57 GHz of overall bandwidth. In the feeding network, silicon is used for increasing the bandwidth, and low dielectric material is applied under patch for decreasing the dielectric loss. Symmetrical parallel feeding networks are employed for high gain of the antenna. The overall antenna size is compatible with miniaturised devices and it has the size of is printable at 6.7 mm by 30 mm with a height of 1.2 mm.

E. Shorbagy et al.[62], in 2016, presented a mm-wave antenna design for 5G mobile network. The research specified the recent trends in the antenna design for mm wave applications. The paper described the four different designs with the possible features in 5G application scenario. In the first design a circularly polarised slotted antenna is presented and showing the resonance at the frequencies of 28 GHz and 38 GHz. This design is excited with microstrip feeding method. The second design emphasised on increasing the gain and achieving wide bandwidth. The design is presented with an inverted-F slot structure, which is planer in structure and using single layer dielectric substrate. The third design is p[resented with a T-Shaped antenna showing resonance from 26.5 GHz to 40 GHz of wide frequency in mm band. In this structure, low cost PET substrate was used. The last design is a double MIMO arrays of 2x2 elements, and are orthogonal for resulting polarisation diversity.

F. Jilani et al.[63] in 2017, proposed the idea of collinear arrays antenna system means for mm wave. The design is an extension of the Franklin linear antenna array in two-dimensional geometry. The researchers achieved a tri band to meet the requirements of future 5G systems. The two-dimensional array antenna operates at 28 GHz and 37 GHz to 39 GHz of licenced frequency bands for 5G mobile networks, satellite communications and radio navigation at 33 GHz. The measurement results were taken at these three bands. The proposed design antenna array deals a distinctive show by giving good gain and more than 70 percent of efficiency.

Nanae Yoon et al.[64] in 2017 examined a U-slot array antenna for a wide wireless system, with the design focussed at 28 GHz of frequency. The array structure is a dual U slot one.

The second U slot provides an additional 10 percentage bandwidth. The gain is further increased by utilising 2x2 array structure. The overall dimension of the proposed design is 41.3 mm x 46 mm x 0.508 mm. To prove the design's reliability, the measurement works has been carried out resulting a gain of 13 dB and a bandwidth of 3.35 GHZ at 28 GHz of resonating frequency.

Sunthari et al.[65] in 2017, proposed a 4 linear array structure based MIMO antenna design. The antenna resonate at quadruple bands in the mm wave region. The resonance in the simulation work are at 28 GHz, 37 GHz, 41 GHz and 74 GHz of frequency and claimed to be in the frequency proposal for the 5G mobile system. The antenna is designed based on the resonant cavity model the multi band resonating frequency are achieved by using the slot and slit elements on the radiating patch and the foundation of the design work of the researchers is resonant cavity method. The feeding technique is inset fed microstrip line. The array structure are positioned taking the half wavelength space diversity technique in the design and the array design yields more than the single unit design of the antenna.

In 2018, Sivasakthi et al.[66] suggested the introduction patch antenna for usage in 5G technology. This proposed antenna is appropriate for the frequency of the millimetre wave as well as wireless LAN. The design is a H-slot circular polarised radiating patch energised with a feeding of the 50 ohms microstrip line used. A Flame Retardant 4, with a height of 1.6 mm, is chosen in as substrate for the simulation work for the single band antenna on High Frequency Structure Simulator. The initial design frequency was 15.4 GHz and it is further extended to 30.2 GHz of mm wave region. The simulated antenna has a return loss of -33.96 dB at the resonating frequency.

In 2018, Mashade et al.[67] proposed a MIMO antenna system for the 5G mobile communication era. The design also used the concept of adaptive beam-forming architectures, as commonly employed at higher frequencies. The researcher claimed this to be one of the key factors in disabling some of the challenges faced out at mm-wave propagation. The combine duse of this technology and MIMO structure may increase the efficiency of the spectrum, as most frequency bands of 5G are expected to be in the 20 GHz to 50 GHz of frequency range. More specifically, it is predicted that the 5 G frequency band will extend from 28 GHz to 38 GHz. The design presented in the concern with the analysis of four 28 GHz antenna array components. The use of low cost FR4 material in the designing of the microstrip antenna yields a satisfactory operation in terms of its efficiency and subsequently maintain the gain. In addition, the simulation results show the response in the 22 GHz to 34 GHz of frequency range of the mm wave region.

In 2018, Smriti Agarwal et al.[68] presented two design antenna. The first one is a single-band mm wave antenna at W band having frequency at 94 GHz (W band) and the second one is a dual-band mm wave antenna having resonance at 60 GHz of V band and 86 GHz of E band off mm spectrum. The design antenna are a simple coplanar waveguide (CPW) in structure, and its measurement results are also presented. The manufactured single-frequency 94 GHz antenna has an 11.2 percent fractional bandwidth and giving gain of 6.17 dBi and 6.2 dBi at E-plane and H-plane respectively. The dual band second design shows a 6.4 percent of bandwidth and gain of 7.29 dBi in E-plane and 7.36 dBi in H-plane respectively for 60 GHz of frequency. The gain for 86 GHz of frequency is 8.73 dBi in E-plane and 8.68 dBi in H-plane respectively. The design antenna is meant for mm wave applications.

Kiran et al.[69] in 2018 proposed a microstrip patch antenna for future 5G wireless communications. The design antenna has 11 mm x 8 mm x 0.5 mm compressed structure, including the ground plane. This antenna is designed using the thin RT Duroid (Rogers 5880) substrate of dimension 4.4 mm x 3.3 mm. The thickness of the substrate is 0.5 mm and its dielectric constant is 2.2. At frequencies of 28 and 50 GHz, this microstrip patch antenna resonates. By using a high frequency structure simulator, the antenna is simulated, and the gain obtained is 2.6 dB. The simulation work showing the antenna structure and various specifications including return loss, VSWR, gain and radiation pattern.

In 2018, Siri Chandana et al.[70] presented a single band microstrip antenna having its usage in 5G mobile system. The work is demonstrated for the usage in the millimetre wave region in the designing of the antenna. The designed antenna consists of two slots, one is E shape in structure and another is with a H shape structure. The radiating patch is excited with a 50 ohm microstrip feed line, and the antenna is designed using Rogers RT5880 material as substrate, whose dielectric constant is 2.2. The antenna design and simulation is completed on HFSS simulation platform. The result of different parameters are discussed in the simulation work. At the 59 GHz of frequency in the millimetre wave region, the design antenna achieved a high return loss of -42.4 dB.

Firdausi et al.[71] in 2018 demonstrated a multi band, three resonating bands, microstrip antenna for 5G broadband applications. This structure of the design has 3 x 3 rectangular patches and branch feed line. The researchers aim is to optimise antenna bandwidth using double feeding coupling shape. The tri-band frequency range of antenna cover from 40 GHz to 70 GHz. The results shows The resonance with god return loss at 45.3 GHz, 57 GHz, and 66 GHz of frequency respectively. The authors use of the combination of technique in the design purpose put the antenna is a hopeful contender for 5G wireless systems.

Neha Kothari et al.[72] in 2018 proposed a U-slot structure patch antenna to be use in 5G wireless system at the frequency of 28 GHz. The principle in taking U slot structure is for minimising the dimension of the antenna. In the design process, the researchers use coaxial feeding method. The proposed antenna is simulated using HFSS simulation software to produce the best possible result. The common advantage of using microstrip patch antennas are also discussed. To prove the design eliability, the fabricated antenna results were calculated and compared. The parameter performance of the designed antenna was analysed at a frequency of 28 GHz.

Yusnita Rahayu et al.[73] in 2018 discussed a single, two, four and six element antenna design. The proposed antenna array is a dual band in nature at 28 GHz and 38 GHz of frequency in the mm wave region. The design is done using Rogers Duroid 5880 substrate of dielectric constant 2.2. The thickness of the substrate is standard and it is 1.575 mm. The bandwidth of the design antenna is enhanced by cutting a triangular slot structure on the ground plane. Amongst the four array types, six element array provides the maximum gain at both the bands of resonating frequencies. The gain at 28 GHz of frequency is 7.47

dBi and at 38 GHz of frequency its value is 12.1 dBi. The return loss value at 28 GHz of frequency is -30.70 dB and its value at 38 GHz of frequency is -34.5 dB.

In 2018, Shengjie Wu et al.[74] has presented a dual-band mm wave antenna array for 5G communication system. The dual-band antenna consists of a monopole branch and a patch that are printed on a cavity-backed ceramic block. The first resonance is generated by using coupling between the monopole and the patch, and the second resonance is generated by the monopole itself. The antenna can be mounted on a printed circuit board. Simulated antenna return loss indicates that the proposed antenna can meet the requirements of the two potential fifth generation (5G) mm wave bands (26 GHz and 40 GHz of frequency) in China. Beam scanning performance of an eight-element antenna linear array is presented for the above two bands.

A. Mahabub et al.[75] in 2018 proposed that for 5G mobile applications, the communication device currently includes multiband small antennas. Their work suggested a multiband antenna for various sub 6 GHz wireless application. The proposed antenna will act effectively at 2.4 GHz for Wi-Fi usage, 7.8 GHz of frequency is the choice of WiMAX application and the design antenna resonance at 33.5 GHz makes its connectivity with 5G application. The bandwidth achieved at these three frequency zones are 235 MHz, 152 MHz and 4500 MHz respectively. Therefore, the designed antenna is proposed for multiband applications that can not only be powerful for usage in 5G, Wi-Fi and WiMAX.

Hala et al.[76] in 2019 proposed a dual-band printed MIMO antennas. The proposed antenna is resonating at 28 GHz and 38 GHz of frequency, and it is suitable for 5G mobile applications. In the first design, a two-element traditional rectangular shaped patch structure is used, and it is loaded with inset feeding method. In the second design, symmetric dual-band two-element MIMO slotted is proposed. The dual is achieved by using inverted I-shaped slots structure in the primary design. The third configuration is a symmetrical four-element MIMO dual-band antenna and is consisting of rectangular inverted I-shaped slot structure on the patch of the antenna. In the partial rectangular ground plane, a slot-formed defective ground slot is inserted. The size of the substrate is 55 mm by 110 mm.

the researcher claimed that though the antenna size is big but antennas implemented is easier to suit for the upcoming 5G mobile communications. Better return losses and high bandwidths are also realised in the design. The MIMO antennas array have low mutual coupling without using any added structures. With expected reflection and correlation coefficient characteristics that appear to be for 5G mobile applications, the antenna systems give acceptable values of in terms of directivity, gain, and radiation efficiency. The antenna is fabricated using a photolithography method and measurement are taken by Vector Network Analyzer with a port impedance of 50 ohm.

In 2019, Misbah Un Noor et al.[77] proposed a lightweight, mm wave antenna array for 5G mobile The 26 GHz to 42 GHz of frequency in Ka band and the 40 GHz to 75 GHz of frequency in V band require a dual band frequency from a single antenna for their use. The substrate chosen for the design work is Rogers RT5880LZ having a thickness of 0.787 mm.. The traditional patch antenna is of dimension of 3mm by 3 mm. The second band of frequency at 50 GHz is achieved by using two rectangular slit along with a circular slot on the patch. In this suggested 2-to-1 antenna array configuration, the criteria for design purpose was fulfilled. The feeding method for the array structure is coaxial feed line feeding of corporate feed network. The gain realised at 30 GHz is of 10.2 dB, whereas its value is 11.6 dB at 50 GHz of frequency. The return loss value is at these two frequency bands are -12.5 -14.85 respectively. The array exhibits a bandwidth of 2.093 GHz at 30 GHz of frequency and 1.764 GHz at 50 GHz of frequency.

Surajo Muhammad et al.[78] in 2019 has demonstrated a single feed dual band antenna for 5G application operating in the 28 GHz and 38 GHz of frequency under mm wave band with an improved efficiency. The antenna is designed and simulated on Computer Simulation Technology (CST) platform using FR-4 substrate having thickness of with 0.8 mm. The dielectric constant of the FR4 substrate is 4.67 and loss tangent value is 0.002. The total size of the antenna is 8 mm × 8 mm, the rectangular radiator is 3.4 mm × 3.4 mm in size, where an inverted-L is introduced into the radiator to achieve dual-band capability. The antenna is fed through 50 Ω feed line probe of about 2.3 mm × 0.4 mm in dimension. The results of the simulation shows that the antenna achieved wide bandwidth in the upper band (38 GHz) of about 3.54 GHz (35.56 GHz – 39.12 GHz) with over 6 dB gain and in the lower band (28 GHz) it produce a bandwidth of about 1430 MHz (27.27 GHz – 28.70 GHz). The gain of the proposed design is 2.7 dB.

In 2019, Choman Khalid Ali et al.[79] investigated a double resonating band microstrip antenna array . The proposed antenna operates at the resonance frequencies of 24.9 GHz and 28 GHz of the mm wave spectrum band. The bandwidth obtained at the two bands are 0.3 GHz and 0.9 GHz respectively. The simulation work was accomplished using CST software. The size of the array designed by the researchers is 9 mm by 8 mm by 0.64 mm. the design antenna array yields a peak gain of 8.42 dBi. The authors claimed the usage of this model in 5G smartphones device. The substrate chosen in the design is RO3210 due to its excellent performance with this design.

In 2019, Pierre Moukala Mpele et al.[80] presented a dual-band microstrip antenna. The feeding method used in the design is coplanar waveguide feeding. The proposed antenna is designed and analysed using a finite element method full-wave simulation. The design contains adual layer substrate. The lower substrate chosen for the design is Rogers RO4350B, having the dielectric constant of 3.66, and the substrate material for the upper surface is Rogers RO3010, whose dielectric constant is 3.5. The size of the elliptical shaped patch is 2.265 mm x 2mm x0.75mm. the dual band is resonating at 28 GHz of frequency and 38 GHz of frequency in the mm wave band of spectrum. The International Telecommunication Union for the 5G cellular technology assigns the two selected bands. The results of the simulation display 4.14 GHz of wide bandwidth with a gain of 6 dB over the range of operating frequency. Additionally, for the proposed elliptical antenna, previous electrical parameters were selected, together with the return loss and VSWR, and thes e parameters were further improved by using two F-shaped slots into the ground plane as a part of defected ground configuration.

In 2019, Mohammad Lutful Hakim et al.[81] suggested multiband patch antenna array. The array is of 2x2 structure and the simulation is carried on CST software tool. The multiband are obtained in the frequency range of 24GHz to 85 GHz. In this entire zone, six bands were achieved by the simulation work. The researcher claimed the design antenna to be low cost, light and useful in finding its application in 5G technology because of the fact that the broadband antenna performance is required for future upcoming 5G wireless communication. Similarly, it is highly desirable for multiband antennas to go with one unit for different bands rather than many units of antenna. The design antenna offers a maximum gain of 15.63 dB and a minimum gain of 9.23 dB in its operating frequency range that lies in between of 26.82 GHz and 34.60 GHz. The total bandwidth is 11.84 GHz for all operating frequencies, and the radiation efficiency is 96 percent. The overall antenna size is 20.66 mm x 22.56mm x 0.67 mm, making it standardised for 5G communication requirements to work better.

In 2019, Chong-Zhi Han et al.[82] proposed a mm wave based microstrip antenna. The designed antenna is a broad band and claimed to be suitable for broadband mm wave wireless communication. The feeding method used in the design is coplanar waveguide feeding structure. For 5G millimetre wave applications, the antenna operating bandwidth is covering both of the 28 GHz and the 39 GHz frequency. The antenna is a array antenna of eight-element. The array beam is showing good radiation from -30° to 30°, and it is suitable for the 5G wireless communications beamforming requirement.

In 2019, Md Nazmul hasan et al.[83] unveiled a planar dual band mm wave antenna at 28 GHz and 38 GHz of frequency. Their design work is a MIMO antenna array of 2 x 2 structure. The frequency chosen is as per the proposed band of frequency spectrum laid down by ITU-R for the 5G communication. The size and shape of the design is based on first band. In order to further increase the surface current density and achieved the second resonating band, at 38 GHz of frequency, the radiating portion slender in a hemispherical structure. The two bands are resonating from 26.65 GHz to 29.2 GHz of frequency and 36.95 GHz to 39.05 GHz of frequency in the mm wave region. The value of the peak gain obtained is 1.27 dBi at the first band, and 1.83 dBi at second resonating band respectively. The radiation pattern measured from the fabricating antenna prototype is omnidirectional in nature. Additionally, the proposed MIMO antenna 's diversity efficiency is measured in terms metrics parameters.

Omar Darboe et al.[84] in 2019 designed a patch antenna to fulfil the need of compact, high-speed, and broad bandwidth systems, as demanded by the specifications of fifth generation communication systems. The antenna was designed for an operating frequency of 28 GHz and the design process of the rectangular microstrip patch antenna was proposed with simulated analysis. The patch has a 6.285 mm x 7.235 mm x 0.5 mm compact structure. The antenna produces a return loss of -13.5 dB at 27.954 GHz of frequency. Its bandwidth is 847 MHz bandwidth. The gain of the simulated design is 6.63 dB gain. For the feeding purpose and energising the radiating patch with source, an inset feed microstrip line is employed. The thin substrate used in the design work is Roger RT Duroid 5880 of 0.5 mm in thickness. The antenna geometry and the simulated results were presented and analysed using the Microwave Studio Computer Simulation Technology.

In 2019, Viswanadh Raviteja [85] addressed the microstrip antenna array design structure. The target frequency range of the proposed array structure is proposed antenna array is 24.25 GHz -27.5 GHz and 26.5 GHz - 29.5 GHz of frequency, and it is intended for the applications with millimetre waves spectrum specification. The Rogers RT Duroid 6002 is the dielectric substrate used in the design work. A typical antenna is initially planned and simulated, and later on 2 x 1 array is implemented, and analysis were done for the different radiation characteristics of both designs. In the last phase of the work, another 2x1 array is attached. Thus the final proposed design is a double array structure back to back. The S parameter of the dual-band 4-element antenna array is -32.88 dB at 24.67 GHz of frequency. In the second frequency of 29.35 GHz, the s parameter is -35.07 dB. The gain at the two regions are 8.67 dB and 10.3 dB respectively. The parameters of all design phases were tabulated for the comparison purpose.

In 2019, Khan et al.[86] designed a Y shaped microstrip antenna for the future Fifth Generation 5G cellular communication system. They investigated the proposed by comparing with a tradition designed antenna consisting of electromagnetic band gap structure. The Y slot loaded designed antenna is made to resonance at 38 GHz of frequency. Rogers-5880 substrates of dielectric constant 2.2 and a thin thickness of 0.254 mm is used in the purpose of design. The antenna showed a good bandwidth of the order of 870 MHz at the frequency of 38.06 GHz, and makes it suitable for working in mm wave region. The bandwidth is enhanced to 1.23 GHz using electromagnetic band gap structure in the ground plane. The normal antenna in their design provides a gain of 6.59 dB and it is increased to 8.91 dB with the slot structure. The simulation work were done using CST software tool.

In 2019, Abdelaziz et al.[87] proposed multi band antenna operating at three resonating frequency. The compact antenna dimension is 20 mm by 16.5 mm and the substrate used in the design purpose is a thin Rogers RT5880 material. The thickness of it is 0.5 mm and its dielectric constant is 2.2. the impedance matching for good bandwidth and return loss is accomplished by partial ground plane design and the feed is utilised by microstrip feedline. The proposed antenna operates at three of the chosen frequencies of 10 GHz, 28 GHz and 38 GHz, which are allocated for 5G mobile communications by the International body regulating the frequency spectrum. The unwanted frequency were rejected by the inclusion of a T-shaped slot on the radiating part of the microstrip antenna, so that the bands are isolated. The value of gain obtained at these three bands are 5.67 dB, 9.33 dB and 9.57 dB respectively with a directional radiation pattern.

Prachi Gupta [88] in 2020 proposed a compact design for the 5G wireless communication system. In her research work, the antenna is a thin profile broad band patch antenna. The size of the compact design is 5 mm x 5.26 mm, and a thin RT Duroid substrate of thickness 0.254 mm is used in the work. The operating frequency of the antenna is kept at 28 GHz. The antenna has a bandwidth of 2.1 GHz, and its operating range is from 27.3 GHz to 29.2 GHz of frequency. For the design work, the antenna is energised with coaxial feed line of radii 0.254 mm. The aim of the design work is in increasing the bandwidth and it was accomplished by using X shape slot in the ground plane, thus utilising the concept of defective ground structure. The slotting technique helps in the matching of high impedance, and it yields a reflection coefficient of -20 dB. The proposed antenna offers a gain of 5.2 dB and a directivity of 6.16 dB respectively. In order to research antenna characteristics, different parameters of were analysed, keeping the implementation for 5G applications

H M Marzouk et al.[89] in 2020 presented a design of MIMO antenna structure. The design work is air-filled-slotted-loop antenna and the working frequency is kept at 28 GHz and 38 GHz of frequency. These two frequencies are the most common band proposed for the next 5G generation of cellular mobile networks. Low-cost FR-4, of dimension 55mm by 110 mm with a standard height of 1.6 mm, is used as substrate material in the antenna design work. Dual-band is achieved by using air filled slot loop structures in the radiating patch. The antenna design is consisting of three of such slotted elements at the top edge and three such elements in the lower part. The design is resonating from 27.7 GHz to 28.7 GHz of frequency and 37.3 GHz to 38.6 GHz. The impedance bandwidths obtained at 28 GHz is 3.5 percent and that its value is 7 percent at 38 GHz of frequency.

2.3 Chapter Summary

This chapter presented an elaborate literature review on different methods used for the designing of the antenna in two region. One of the region is sub 6 GHz and another on is mm wave region. The techniques used by different researcher are focused on designing single band, dual band and multiple band antenna. The location of required resonating frequency is the main objective of the researchers. The different ways of achieving the resonance and improving the performance of the antenna are fractal method including planer slot structure, ring slots, and concentric split ring slot structure.

The studies of all this literature review help us in the designing of the multi resonance antenna for our thesis work. All this literature review focused on the area of the researcher choice and the operating frequency as per the requirement. Our design is following the frequency projected by the proposal drafted by the Department of Telecommunication, hence this literature review has a gap of not covering the 5G bands along with the LTE bands only.

Chapter 3

DESIGN OF MULTI BAND ANTENNA IN SUB 6 GHz

3.1 Introduction

This chapter presents the design, optimization, fabrication, and measurement of an inverted-F slot microstrip antenna for sub 6 GHz band for proposed 5G application. In this investigation, inverted-F slot on the antenna patch is designed to get the multi band operations with higher order of miniaturization. Impedance matching is improved by using stub matched technique at the feedline. The designed antenna shows a good resonance at precisely 2.1 GHz, 3.3 GHz, and 4.1 GHz of frequency with a good reflection coefficient. The gain of each band is more than 5 dB.These three frequencies are chosen for LTE (2.1 GHz), n78 band of 5G (3.3 GHz) and n77 band of 5G (4.1 GHz) respectively as projected by Department of Telecommunication, Government of India proposal for 5G application.

The proposed antenna geometry considers a square fractal aperture with microstrip line feeding. The feeding is optimized with stub matching to improve the reflection coefficient characteristics and to provide operability in the proposed 5G application in the single antenna. The said square aperture of the antenna is first disturbed by Inverted-F slots at the diagonal corner to improve the performance of the antenna. Secondly, a square shaped split ring slot is dogged just after the feed line, which cooperatively improves the radiation characteristics of the designed antenna. The designed antenna demonstrates three bands of resonance, the first one is at 2.1 GHz, second one at 3.3GHz, and the third one is at 4.1 GHz of frequency. Typically gain at each resonance is enhanced to more than 4 dB and all the three bands shows a good radiation pattern. The combined fractal and slotted configuration realize multi-band operation applicable for mobile communication system. This antenna exhibits tremendous application in mobile cellular communication such as LTE band (2.1 GHz) and 5G-NR (3.3 GHz and 4.1 GHz) communication bands.

3.2 Configuration of Multi Band Antenna in sub 6 GHz

A compact microstrip inverted-F slotted fractal antenna for Mobile and 5G-NR application is presented in this chapter. In this investigation inverted-F slot on the antenna aperture is analyzed to demonstrate multi-band mobile operations with higher order of miniaturization. To improve the impedance matching at multiband characteristics, a stub-matched technique is introduced with offset feeding. The simulation work has been carried out in Ansys HFSS v.19 platform.

The proposed microstrip antenna is designed on a single dielectric substrate. The substrate chosen for the this design is RT Duroid (RT 5880) substrate. The dielectric constant of the substrate is 2.2, and loss tangent is 0.009. The use of substrates of low tangent losses will minimize dielectric losses, but these substrates are more costly. The height of the substrate is taken as 1.57 mm, and using this moderate thicker substrates, conductor losses may also be minimized, thereby influencing the performance of the antenna. This RT-Duroid substrate, though expensive, enhance the performance of the antenna in terms of reflection coefficient and gain. The aim in choosing this specification is to design a multi band antenna with good gain, reflection coefficient and directive radiation property. The design is proposed to find its scope in modern wireless mobile communication system. Primarily the physical dimensions are determined using the equations given below [90].

The width of the patch, Wp, is given as:

$$W_p = \frac{c}{2f}\sqrt{\frac{2}{(\epsilon_{r+1})}} \tag{3.1}$$

The length of the patch, Lp, is given as:

$$L_p = L_{eff} - 2\Delta L \tag{3.2}$$

Here, the effective length, Leff, is as below:

$$L_{eff} = \frac{c}{2f}\sqrt{\frac{1}{\epsilon_{eff}}} \tag{3.3}$$

The effective dielectric constant, $\epsilon_e ff$, of the substrate, is given as:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{[1 + 12\frac{h}{W}]} \tag{3.4}$$

The design flow of the proposed antenna gone through few iterations. A conventional rectangular patch is implemented on the top surface of dielectric wherein a fully conductive ground is considered.

3.3 First Design Structure with Fractal Slots

The layout and geometric structure along with the critical parameters of the proposed dual-band fractal-slotted antenna is illustrated in figure 3.1. In the first iteration, fractal slots are etched at the opposite boundary along the length of the patch as shown in the figure. Fractal slot is derived from the word fractal meaning self-identical and broken irregular pieces. They belongs to a family of complex shapes that possess an intrinsic self-similarity in their geometrical structures [91]. A fractal slot carved on the on the edge along the length of the antenna produces different frequency bands owing to its repeating geometry structure.A microstrip patch antenna embedded with a changed fractal design rendered a dual-frequency device possible for better performance.The dimension of slots has been shown in the table 3.1

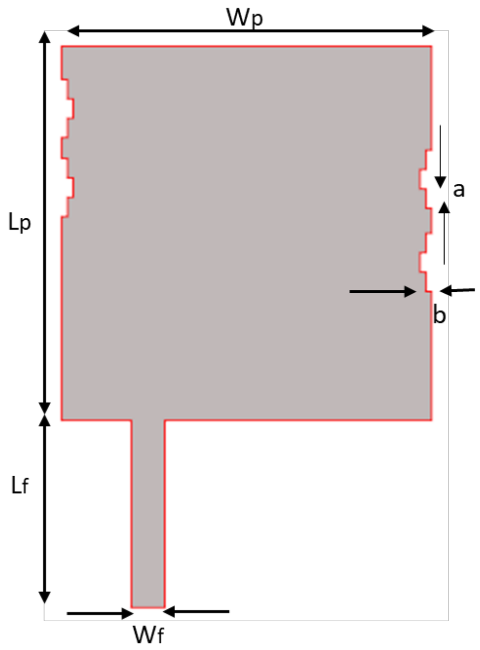

Figure 3.1: Layout of first design with fractal slots on boundaries

Parameters	**Values (in mm)**
Substrate Height (h_s)	1.57
Patch Length, (L_p)	45
Patch Width, (W_p)	45
Feed Length, (L_f)	22.5
Feed Width, (W_f)	4.1
Fractal slot, (a)	2.3
Fractal slot, (b)	0.7

Table 3.1: Parameter of sub 6 GHz antenna

3.3.1 Results of Reflection Coefficient of First Design

The primary patch antenna of the proposed design integrates with a transmission line feeding technique. This antenna provide the resonance at various frequencies in the band due to fractal design of the antenna. The reflection coefficient patterns are shown in the figure 3.2 below.

Though, this design shows multi bands, but the antenna performance lacks in two distinct parameters. One, the multi resonance is not achieved because the reflection coefficient of two bands are far away from -10 dB mark and second, the excitation are not at the

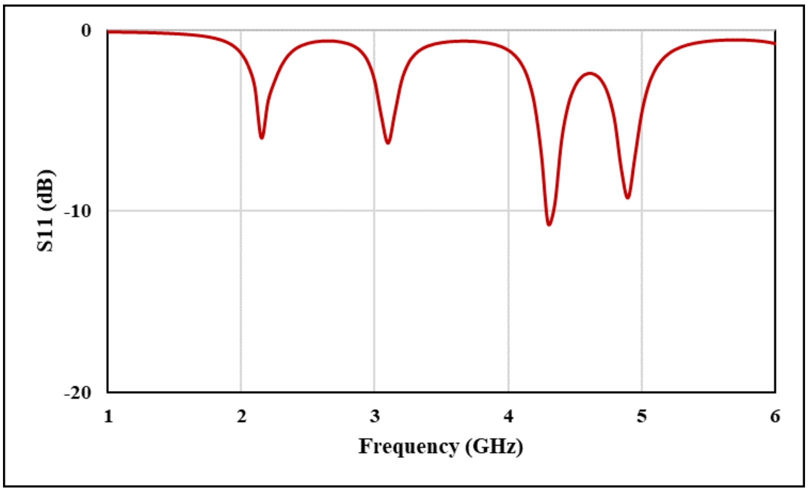

Figure 3.2: Reflection coefficient plot of first design

specified bands. This shortcoming leads to the proposal of the second design.

3.4 Second Design with Inverted F-slot Structure

In the next step of the design iteration, a dual inverted plane F slot is introduced on the radiating patch. This dual inverted-F slotted structure are opposite to each other in position and the antenna structure is illustrated in Figure 3.3. In the current deployed cellular network, the planar Inverted-F antenna is commonly used because of its low profile and ease of placing on the radiating patch [92]. This structure is also used in controlling the frequency and yields moderate to high gain of the microstrip antenna. The impedance matching is improved with this structure as it reduces backward radiation and increases antenna efficiency [93]. In short, this structure consists of radiating patches parallel to a ground that are joined to the ground by a shorting plate to resonate at quarter wavelength.

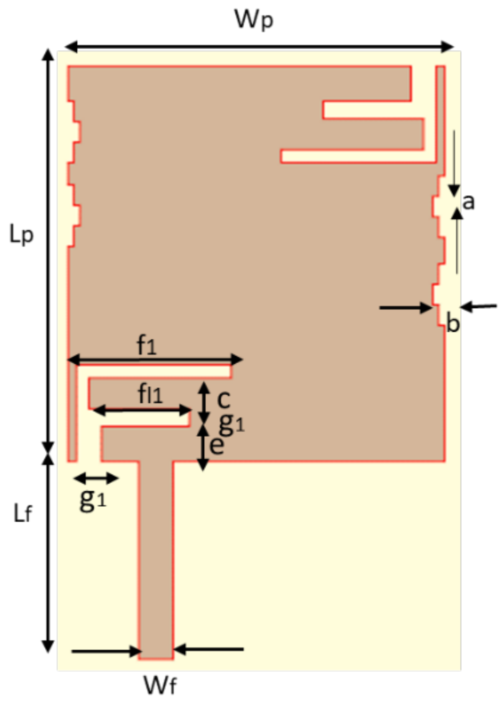

Figure 3.3: Layout of second design with introduction of inverted F-slots

3.4.1 Results of Reflection Coefficient of Second Design

The impact of inverted-F slot over the fractal slot loaded square patch antenna is to bring the first resonance at 2.2 GHz and second resonance at 3.0 GHz. The design antenna also demonstrates a third band around 4.2 GHz of frequency and thus results a multiple resonance in sub 6 GHz band. Analysis has been performed in HFSS simulation tools and the results are demonstrated below. The reflection coefficient plot over the frequency is plotted in figure 3.4. This design brings the first band at 2.2 GHz. The second band also comes to be at 3.3 GHz but its resonance is not good and the radiation is near to -10 dB. The third band is exciting at 4.2 GHz with poor reflection coefficient.

This design achieved in three well distinguishable band, but the second band is not of good reflection coefficient. Moreover, the three bands are still not falling exactly as per the specified frequency. The objective of exact resonance at specific proposed frequency by DoT, enable the structure of third design.

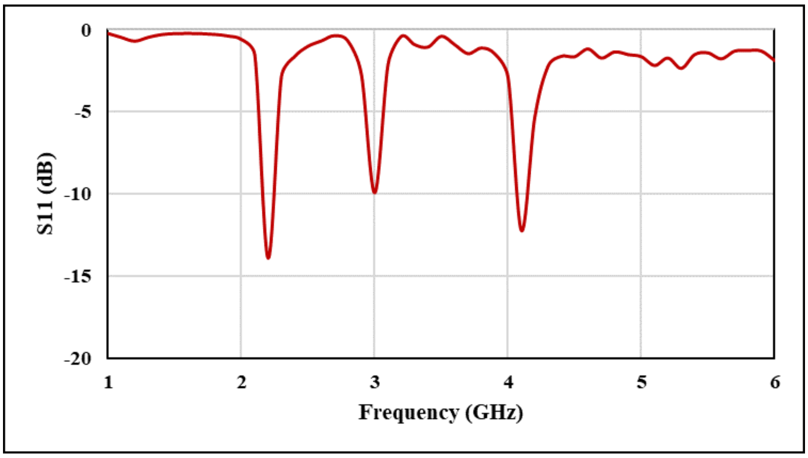

Figure 3.4: Reflection coefficient plot of second design

3.5 Third Design with Stub Matched Structure

Implementation of multiple slots improves the multiband response, but it degrades the impedance characteristics. To improve the impedance response at multiple resonances, stub matching technique has been investigated. Analysis has been carried out using different stub size and position. It has been observed that the change in stub dimension give a large order of flexibility in impedance tuning without disturbing the original resonances. It is realized the stub length (Ls) of 8.9 mm and width (W_s) of 2.5 mm meet the appropriate reflection coefficient response. The structure of this third design is illustrated in figure 3.5.

3.5.1 Results of Reflection Coefficient of Third Design

The reflection coefficient plot over the frequency is plotted in figure3.6. This design brings the first band at 2.2 GHz. The second band also comes to be at 3.0 GHz but its resonance is not good and the radiation is near to -10 dB. The third band is exciting at 4.2 GHz with reflection coefficient near to -10 dB. The introduction of stub matching not only improves the overall reflection coefficient of the three band, but precisely positioned the three bands at the desired and specified frequency.

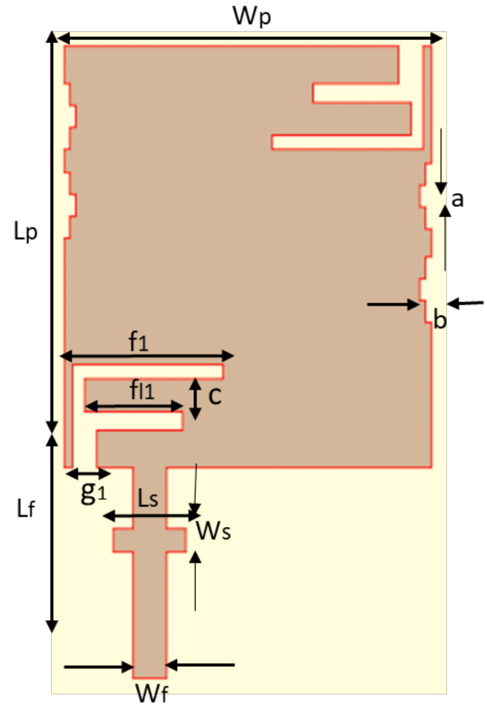

Figure 3.5: Layout of third design with stub matching structure

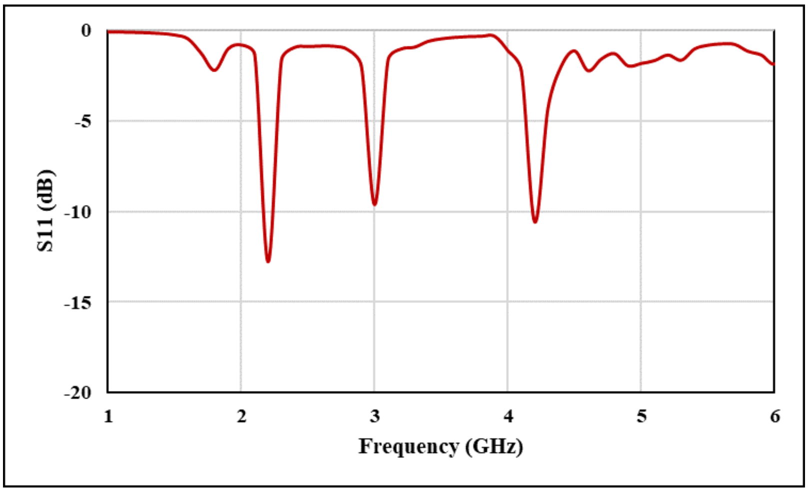

Figure 3.6: Reflection coefficient plot of third design

This design results in bring the frequency of the first and third band at the specified frequency, but the second band is not falling at the desired zone. The improvement is required in this third design for more matching in the impedance between the source and antenna, hence it centrals to the implementation of the final design.

3.6 Final Design with Split Ring Slot Structure

In the last step, a tiny split ring slot is implemented on the patch of the antenna aperture. This is done to further improve the impedance matching of the antenna to get it excited at the specified frequencies [94]. The position of this slot is just at the junction point of feed line and radiating patch. The final proposed antenna design is loaded with fractal slots, inverted- F slot and split ring along with the with a stub matching technique to achieve a fine tuning in impedance profile. All these structure are plane in nature with easily etched on the patch above the ground plane, and the structure of the final designed antenna is illustrated in figure 3.7. The parameters for the final design of the antenna are enumerated below in the table 3.2.

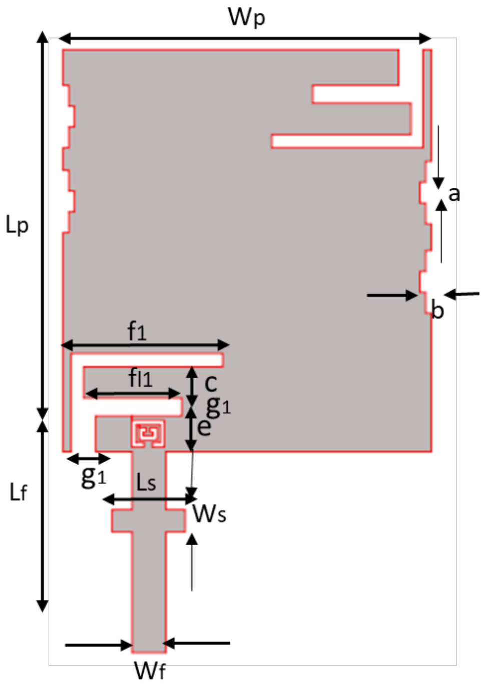

Figure 3.7: Layout of final design of the antenna

3.6.1 Results of Reflection Coefficient of Final Designed Antenna

The reflection coefficient plot of this design is giving the perfect result. Figures 3.8 depicts the simulated value of Reflection coefficients of the final design in sub 6 GHz region. The figure demonstrate that all the three bands are distinguished and they are

Parameters	**Values (in mm)**
Substrate Height (h_s)	1.57
Patch Length (L_p)	45
Patch Width (W_p)	45
Feed Length (L_f)	22.5
Feed Width (W_f)	4.1
Upper arm of F-slot, (f_l)	18.5
Lower arm of F-slot, (f_l1)	12
Fractal slot, (a)	2.3
Fractal slot, (b)	0.7
Gap between F-slot, (c)	3.5
Distance of F-slot, (e)	4
Width of base of F slot, (g_1)	3
Width of arm of F slot, (g_2)	2
Length of stub, (L_s)	8.9
Width of stub, (W_s)	2.5

Table 3.2: Parameter of final designed sub 6 GHz antenna

resonating with good impedance matching. These three bands are at 2.1 GHz, 3.3 GHz and 4.1 GHz of frequency with a reflection coefficient of -28 dB, -21 dB and -24 dB respectively.

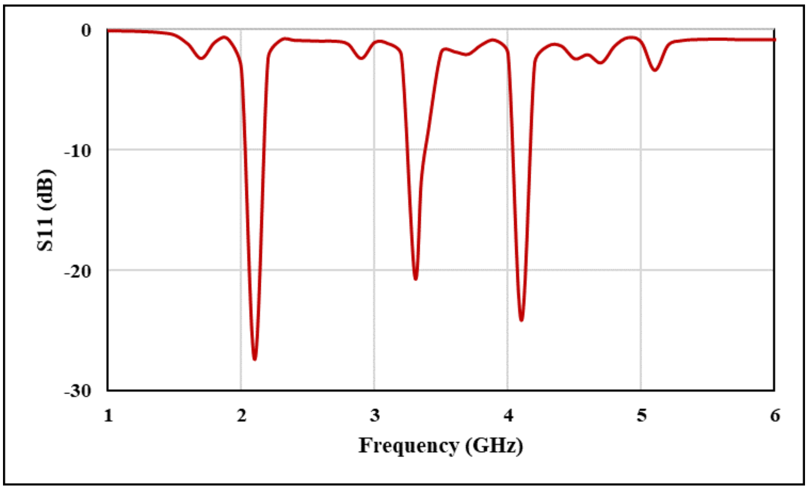

Figure 3.8: Reflection coefficient plot of final designed antenna

3.6.2 Results of VSWR of Final Designed Antenna

The value of Volatge Standing Wave Ratio (VSWR) is plotted along with the frequency and the result is shown in figure 3.9. It indicated that the VSWR is below 2 in between the operating range and indicates the working of antenna within these frequencies. This plot also reveals that the antenna is showing a good ratio of 1:2 of VSWR at three bands. The value of VSWR at 2.1 GHz, 3.3 GHz and 4.1 GHz of frequency are 1.09, 1.21 and 1.18 respectively.

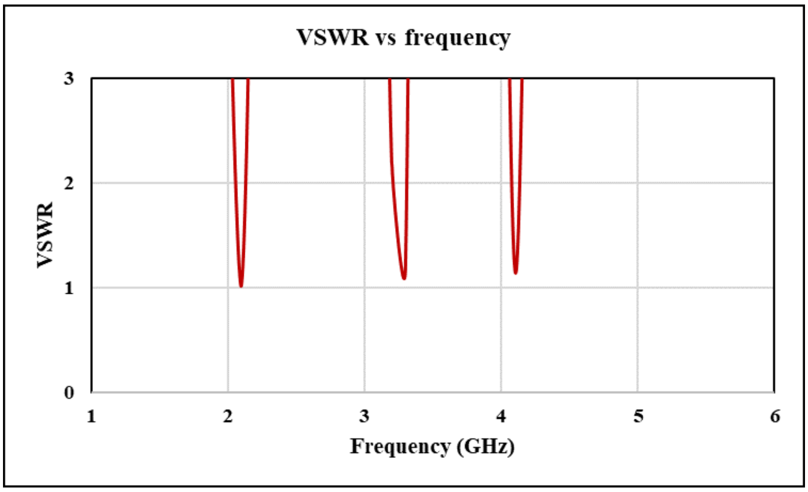

Figure 3.9: VSWR plot of final design

3.6.3 Results of Peak Gain of Final Designed Antenna

The values of peak gain for the simulated design antenna is shown in figure 3.10. The variation of peak gain with frequency depicts that the antenna is showing a good gain response of more than 4 dB in the entire zone of its operating frequency. The values of the peak gain at the three bands are 5.4 dB at 2.1 GHz of frequency, 6.4 dB at 3.3 GHz of frequency and 4.9 at 4.1 GHz of frequency respectively.

3.7 Fabrication, Measurement and Validation of Results

The final antenna is fabricated using RT duriod (Rogers 5880) as dielectric substrate, having with dielectric contact of 2.2, height of 1.57 mm. In the fabrication process, a photographic film of the antenna is carved out initially and then it is glued on the substrate. The radiation patch and the ground plane of the substrate is copper cladded. In the next stage, the antenna is etched out with chemical solution. Finally the fabrication of antenna

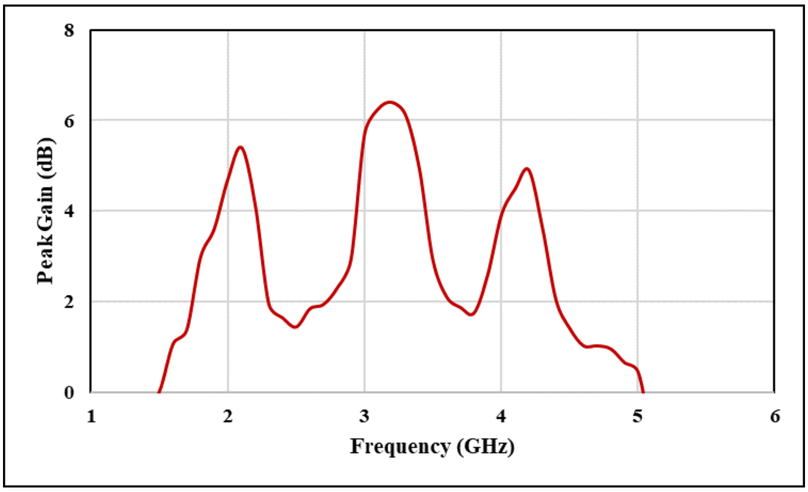

Figure 3.10: Peak gain plot of the final designed antenna

is done by a computerized mechanical etching process and in this process necessary care was taken to align the ground slit exact below the stub matched transmission line. The photograph of the final fabricated antenna is shown in Figure 3.10.

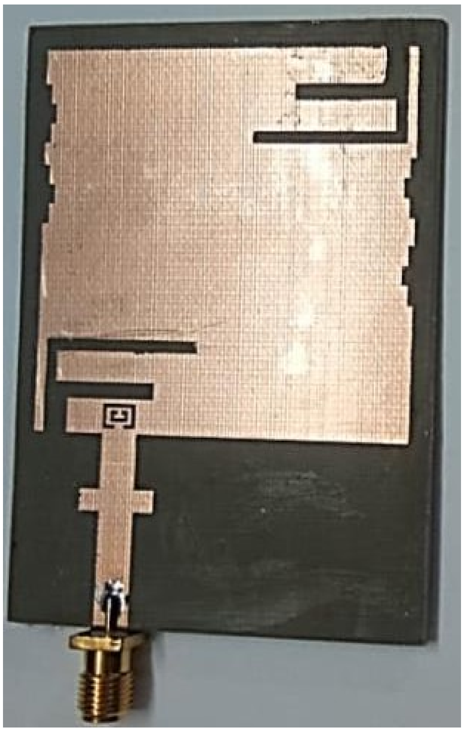

Figure 3.11: Photograph of final designed antenna

The results (reflection coefficient and VSWR) of the fabricated antenna is measured using VNA and its results are validated by comparing with the results of the simulated results. The gain and the radiation are measured in the anechoic chamber. The fabrication and measurement processes are completed at SAMMER and the set up for the measurement in anechoic chamber is shown in figure 3.12.

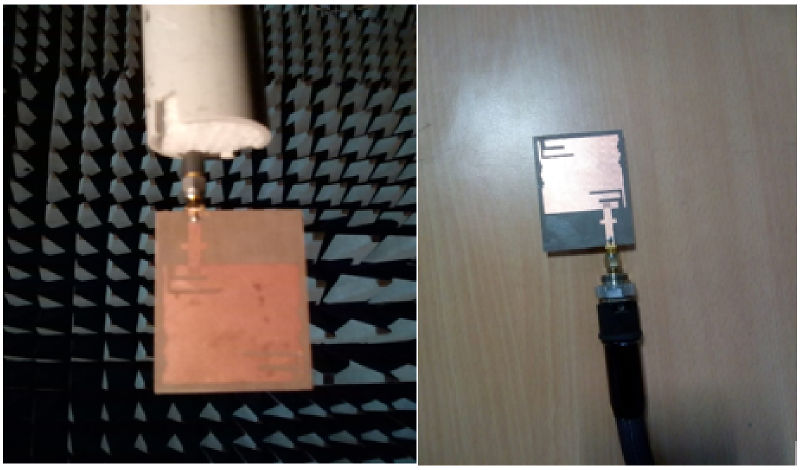

Figure 3.12: Set up for testing and verification of fabricated antenna

3.7.1 Measurement Results of Reflection Coefficient of Final Designed Antenna

The measured values of reflection coefficient with respect to frequency is plotted along with the simulated results and it is shown in figure 3.13. As demonstrated in the figure, the experimental analysis follows the resonance characteristics exactly same as that of the simulation work with a very nominal deviation. The experiment analysis validates the claimed resonances -19 dB at 2.1 GHz, -17 dB at 3.3 GHz, and -18 dB at 4.1 GHz of frequency with better deep.

3.7.2 Measurement Results of VSWR of Final Desigened Antenna

The value of VSWR with respect to frequency is plotted for both the simulated and measured results, and it is shown in figure 3.14. This plot reveals that the antenna is showing a good ratio of 1:2 of VSWR at three bands. The simulated and measured value of VSWR at 2.1 GHz are 1.09 and 1.1 respectively, the simulated and measured value at 3.3 GHz are 1.21 and 1.28 respectively, whereas these values at 4.1 GHz of frequency are 1.18

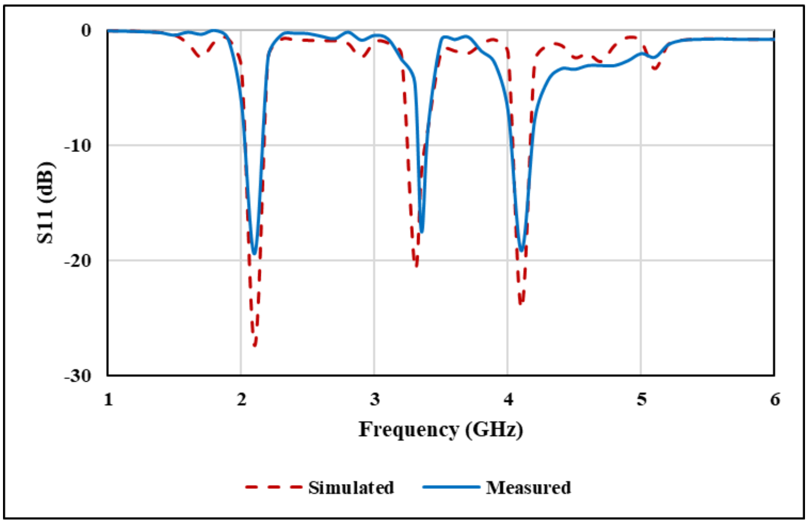

Figure 3.13: Comparison of the reflection coefficient of simulated and measured values of final antenna

and 1.2 respectively. therefore, the value of VSWR is below 2 in between the operating range for all the three bands. The close proximity of measured result and simulated work indicates the validation of the design work. The value of VSWR in the vertical axis of the figure is chosen from 0 to 3 so a sto get the clear graph.

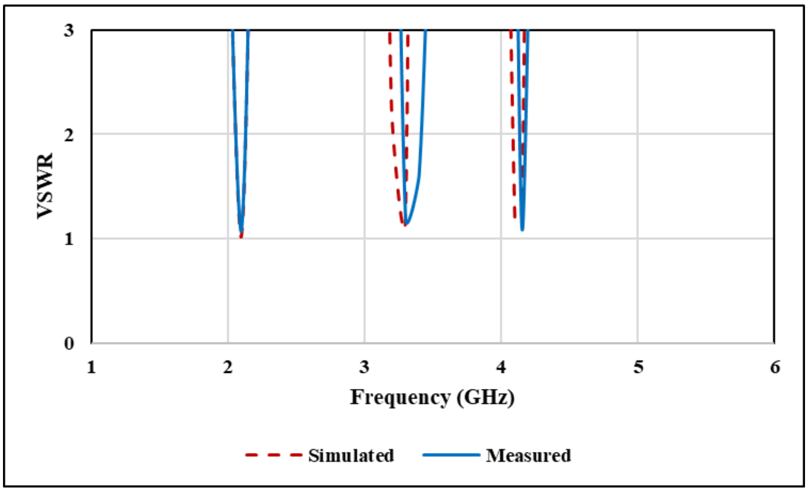

Figure 3.14: Comparison of the VSWR of simulated and measured values of final antenna

3.7.3 Measurement Results of Gain of Final Designed Antenna

The plot for gain response over the frequency range, of the proposed antenna, is plotted in figure 3.15. The peak gain of the antenna is more than 4 dB. The experimental peak gain at 2.1 GHz, 3.3 GHz and 4.1 GHz of frequency are 4.6 dB, 5.5 dB and 4.1 dB respectively.

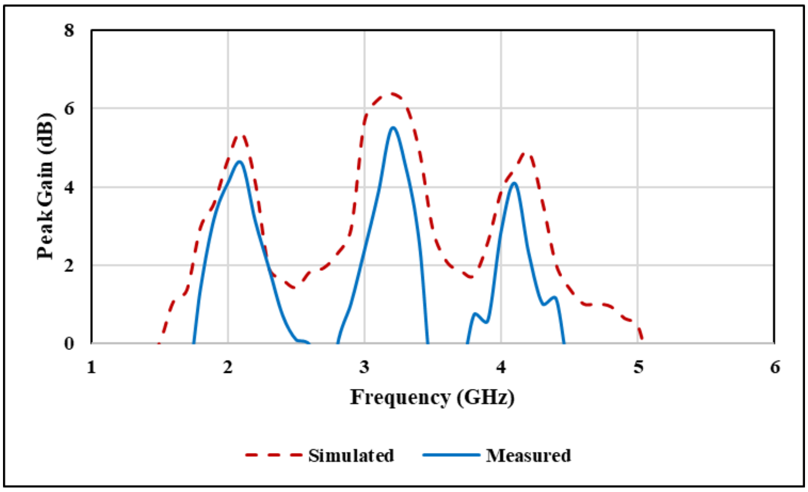

Figure 3.15: Comparison of the gain of simulated and measured values of final antenna

The matching between the simulated and experimental results validate the design of the antenna for gain.

3.7.4 Measurement Results of Radiation Pattern of Final Designed Antenna

The radiation pattern of the antenna is plotted in the far field to precisely observe power propagation, allowing a contrast between the real and theoretical values. In fact we can say that the amount of the power illuminated by an antenna which is function of the orientation of electric field vector is defined by a radiation pattern. It is the most important property of the antenna and is graphed on a polar diagram. It is also known as antenna pattern or far-field pattern and represents the graphical representation of radiated power at as particular distance from the antenna. It depicts about the distribution of power in the space, and in the case of a transmitting antenna, it indicates the strength of the power field radiated by the antenna in various directions.

The measurement set up for radiation pattern for millimeter wave antennas is shown in figure 3.12. In the measurement setup the antenna under test is placed on a turn table and connected to one port of the analyzer for reading. A wideband horn antenna, taken as reference transmitter, is connected to the other port of the analyzer. The turn table is controlled by positional controller and the number of reading is set accordingly.

The radiation pattern at three desired frequency viz 2.1 GHz, 3.3 GHz and 4.1 GHz are measured at the anechoic chamber and the plot of the 2 dimensional radiation pattern is plotted along with the simulation results.

The E-plane and H-plane plot for 2.1 GHz of frequency (both measured and simulated) is shown in figure 3.16 and 3.17 respectively. The radiation pattern of the E-plane demonstrate that the measured results are in accordance with the simulated design work. The maximum radiation intensity is towards the principle lobe of the antenna, and the back lobe is almost null. This shows the directive nature of the radiation. The measurement of H-plane results reveals that the radiation intensity is concentrated more towards the main lobe. The main lobe is dominating with almost no presence of back lobe radiation. Only in the measured result, the value of radiation intensity is less in the back lobe radiation.

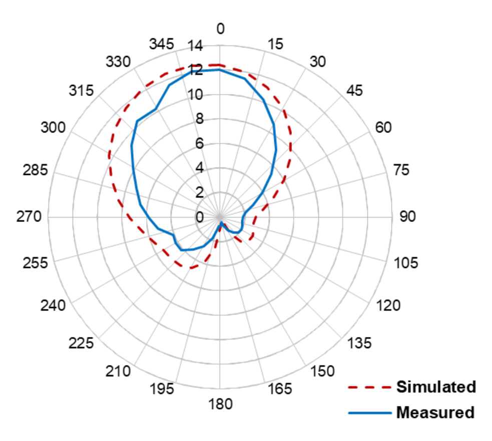

Figure 3.16: E-plane plot for 2.1 GHz

The E-plane and H-plane plot for 3.3 GHz of frequency (both measured and simulated) is shown in figure 3.18 and 3.19 respectively. The radiation pattern of the E-plane exhibits a uniform wide coverage with maximum intensity in the main lobe, and the measured results are in accordance with the simulated design work. The maximum radiation intensity is

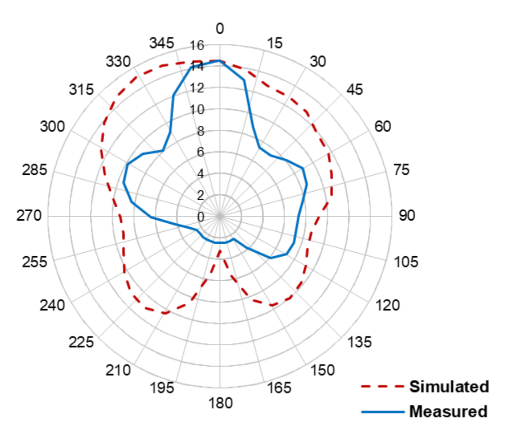

Figure 3.17: H-plane plot for 2.1 GHz

towards the principle lobe of the antenna, and the back lobe is almost null. This shows the directive nature of the radiation. The measurement of H-plane results reveals that the radiation intensity is more in the main lobe. The main lobe is dominating with almost no presence of back lobe radiation. Both the pattern reveals the uniform directive nature of the designed antenna.

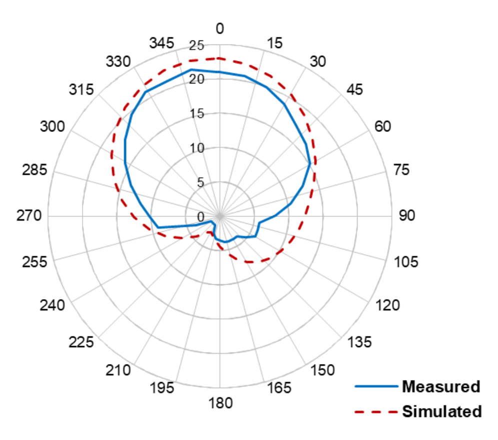

Figure 3.18: E-plane plot for 3.3 GHz

The E-plane and H-plane plot for 4.1 GHz of frequency (both measured and simulated) is shown in figure 3.20 and 3.21 respectively. The radiation pattern of the E-plane is similar to the pattern obtained in the simulated work. The maximum radiation intensity is inclined towards the principle lobe of the antenna, with little radiation towards the back lobe. The measurement of H-plane results reveals that the radiation intensity is concentrated more

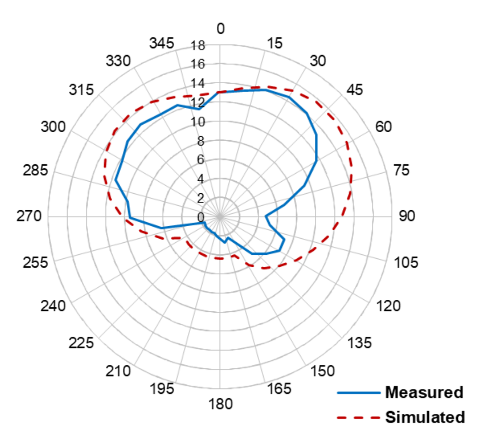

Figure 3.19: H-plane plot for 3.3 GHz

towards the main lobe. The main lobe is dominating with almost no presence of back lobe radiation. Only in the measured result, the value of radiation intensity is less in the back lobe radiation.

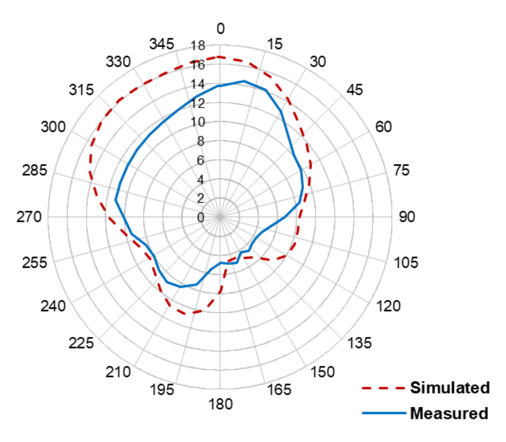

Figure 3.20: E-plane plot for 4.1 GHz

The proposed antenna shows a symmetric radiation pattern with more than 14 dB at various resonance frequencies in both plane. All the radiation intensity plots for the three bands of frequency demonstrate that the measured results are in accordance with the simulated design work.

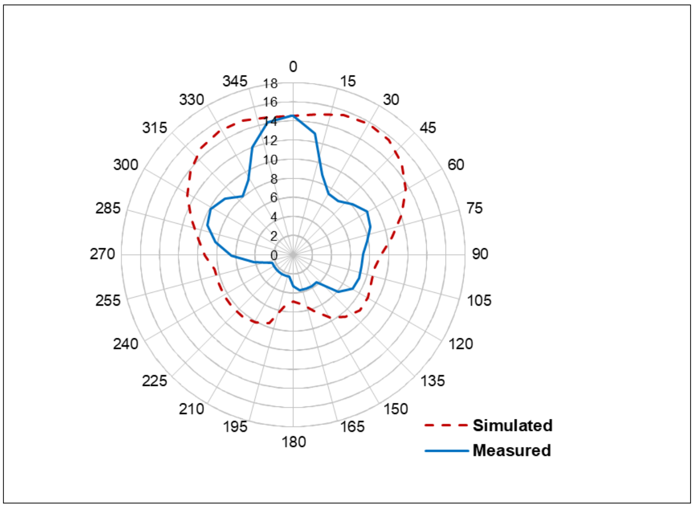

Figure 3.21: H-plane plot for 4.1 GHz

3.8 Summary of Results

Table 3.3 below summarized the simulated and measured results and the matching between the simulated and experimental results validate the design of the antenna.

Resonance Frequency	**Parameter**	**Simulated**	**Measured**
First band at 2.1 GHz	Reflection coefficient	-17.5 dB	-19.5 dB
	VSWR	1.09	1.1
	Gain	5.4 dB	4.5 dB
	Bandwidth	230 MHz	200 MHz
Second band at 3.3 GHz	Reflection coefficient	-20.5 dB	-17.5 dB
	VSWR	1.28	1.21
	Gain	6.4 dB	5.5 dB
	Bandwidth	190 MHz	170 MHz
Third band at 4.1 GHz	Reflection coefficient	-24.5 dB	-19.2 dB
	VSWR	1.2	1.18
	Gain	4.1 dB	4.3 dB
	Bandwidth	220 MHz	200 MHz

Table 3.3: Summary of the simulated and measured results of the final design antenna

3.9 Comparison of Results with Existing Literature

In this section, a comparison of the converged design is presented with a couple of other researcher work on sub 6 GHz of frequency, and it is summarized in table 3.4 Our design work is as per the frequency bands proposed by the Government of India.

References	**Resonating Frequency**	Bandwidth	**S-parameter**	**Gain**	**Dimensions** (in mm^3)
[95]	1.2 GHz 2.45 GHz 5.6 GHz	12.8 MHz 53 MHz 52 MHz	-12.5 dB -20 dB -24 dB	-4 dB 5 dB 6.3 dB	50×50×1.5
[96]	2.45 GHz 3.5 GHz 4.7 GHz	150 MHz 640 MHz 270 MHz	-15 dB -22 dB -27 dB	2.1 dB 2.8 dB 3.5 dB	25×32×1.6
[97]	3.45 GHz 4.9 GHz	300 MHz 200 MHz	-11 dB -20 dB	2.5 dB 5dB	50×50×0.8
Design Antenna	2.1 GHz 3.3 GHz 4.1 GHz	200 MHz 170 MHz 200 MHz	-19.5 dB -17.5 dB -19.2 dB	4.5 dB 5.5 dB 4.1 dB	67×45×1.57

Table 3.4: Comparison of the proposed antenna with existing literature.

3.10 Chapter Summary

This chapter presented the design of a multi-band sub 6 GHz 5G antenna with three bands of operating frequency. The compact microstrip antenna loaded with inverted-F slotted fractal stub matching structure is finds its application in LTE-A and 5G-NR mobile technology. The three bands are precisely as per the DoT specification. In this design process investigation on fractal slots and inverted- F slot on the patch of the antenna is analyzed to demonstrate multi-band with higher order of precision. The symmetrical fractal lies at the edge on the length and inverted-F slots are at the top and bottom of the patch opposite to each other. To improve the impedance matching at multi band fracture of this antenna design, a stub-matched technique is introduced at the junction of patch and feeding. The three resonating bands are at 2.1 GHz, 3.3 GHz, and 4.1 GHz and confirms the VSWR of 1:2. The proposed antenna configuration shows a good gain response up to 5 dB. The antenna exhibits good impedance bandwidth up to 200 MHz, and also shows an enhanced gain of more than 4 dB at all three bands. The radiation pattern also clearly shows the directive nature, and With these viable performances the design antenna claims its efficient application in the three chosen band of frequencies. The performance the design antenna justifies its position in future mobile communication system to cover up the integration of 5G with existing technology.

Chapter 4

DESIGN OF DUAL BAND MILLIMETER WAVE ANTENNA

4.1 Introduction

In this chapter, the design of a compact multi resonance (dual band) microstrip antenna, operating in mmWave region, is presented. The design is accomplished in accordance with the specification proposed by the Department of Telecommunication, Government of India for the 5G communication technology. The proposed antenna is a dual band having resonating frequencies precisely at 28 GHz and 36 GHz precisely. these two frequencies are in accordance with the n257 and n260 band proposed by Department of Telecommunication, Government of India for the 5G technology.

The designed antenna, loaded with two concentric rectangular split ring slots, is excited by microstrip feedline. These slot structure adds a dual-band resonance at the two desired frequency keeping the compactness intact. Furthermore, the impedance matching is further enhanced using a guided slot structure on the feedline at the junction of feedline and patch of the microstrip antenna. The final designed antenna shows a high gain of more than 5 dB, good reflection coefficient in excess of -20 dB and symmetric radiation at the two resonating frequency.

4.2 Design Consideration for Dual Band mmWave Antenna

For the design purpose of the mm-wave antenna, at the specific frequency, RT- Duroid (Roger's-5880) is chosen as the substrate material. Its dielectric constant is 2.2 and the loss tangent is 0.0009. The use of substrates of low tangent losses will minimize dielectric losses, but these substrates are more costly. The height of the substrate, which ultimately limits the height of the antenna, is taken as 1.57 mm, and utilizing this moderate thicker substrate, conductor losses may also be minimized, thereby impacting the performance of the antenna. This RT-Duroid substrate, though expensive, enhance the performance of the antenna in terms of reflection coefficient and gain. The aim of choosing this specification is to design a compact antenna at such high frequency with good gain, reflection coefficient and directive radiation property. The simulation work has been carried out in Ansys HFSS v.19 platform.

In the initial phase of the design, the frequency is chosen as 30 GHz. All the antenna dimensional parameter are near to this frequency. The different parameters of the patch of the microstrip antenna is determined from the given set of equations as stated in equations 3.1 to 3.4 of chapter 3. The patch of the antenna is incorporates edge excitation using microstrip feeding method.

The design flow of the proposed antenna gone through few iterations by considering with a conventional rectangular patch is implemented as the top surface of dielectric and a full conductive ground pane as the bottom surface.

4.3 First Design Structure with Plain Patch

The primary antenna, having rectangular patch, is illustrated in Figure 4.1. Manual optimization is performed on the dimension of the patch of the antenna to acquire the functioning around 30 GHz of frequency. In the same manner, the rectangular and planer feed line is also optimized to get a good resonance response with better impedance. The design flow of the proposed antenna gone through few iterations. A conventional rectangular patch is implemented on the top surface of dielectric wherein a fully conductive ground is considered.

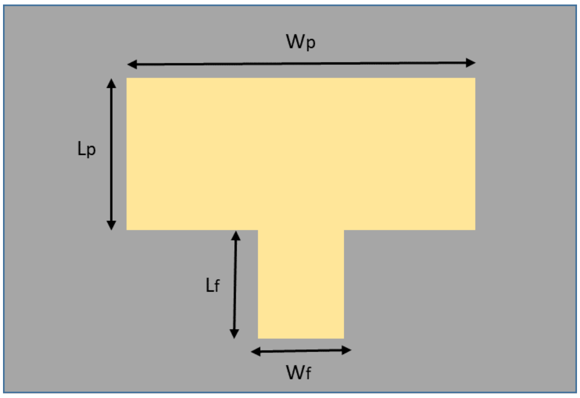

Figure 4.1: Layout of first design of mm-Wave antenna

Different values of antenna parameters are tabulated in table 4.1.

Parameters	**Values (in mm)**
Substrate Height (h)	1.57
Patch Length (L_p)	2.7
Patch Width (W_p)	4.7
Feedline Length (L_f)	1.35
Feedline Width (W_f)	1.1
Substrate Length (L_s)	5.51
Substrate Width (W_s)	7.5

Table 4.1: Parameter of mmWave antenna

4.3.1 Results of Reflection Coefficient of First Design

The simulated value of reflection coefficients (S11) of first design at proposed mm-wave range is shown in figure 4.2. The proposed antenna shows -19.5 dB at 30.2 GHz of frequency. The antenna is resonating from 29.3 GHz to 31.7 GHz with a bandwidth of 2.4 GHz. This antenna design is resonating primarily at a single frequency.

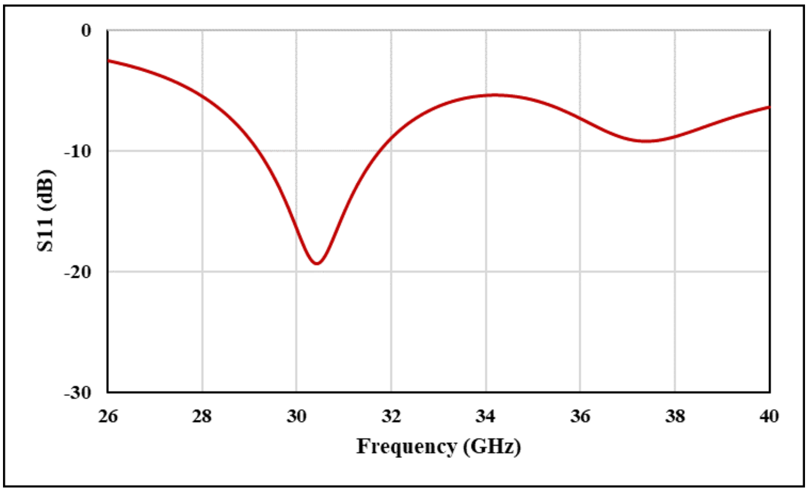

Figure 4.2: Reflection coefficient plot of first design

4.3.2 Results of Voltage Standing Wave Ratio of First Design

The simulated value of VSWR is plotted along with the frequency, and it is shown in figure 4.3. It indicated that the VSWR is below 2 in between the operating range having value of 1.24 at 30.2 GHz of frequency. A value of less than 2 from 29.3 GHz to 31.7 GHz of frequency indicates the working of antenna within these frequencies.

4.3.3 Results of Peak Gain of First Design

A plot of peak gain along with the frequency is presented in figure 4.4. At the frequency of 30.2 GHz, the value of peak gain is 8.0 dB and this design exhibits a high peak gain in excess of 4 dB in the entire zone of frequency ranging from 26 GHz to 40 GHz.

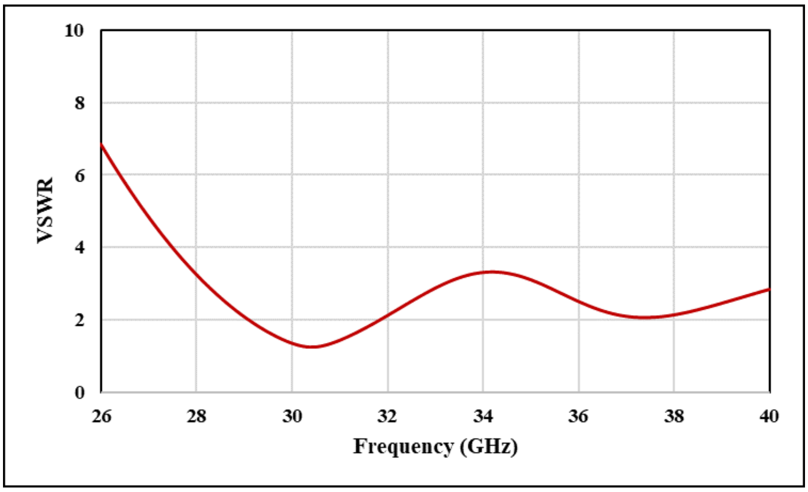

Figure 4.3: VSWR plot of first design

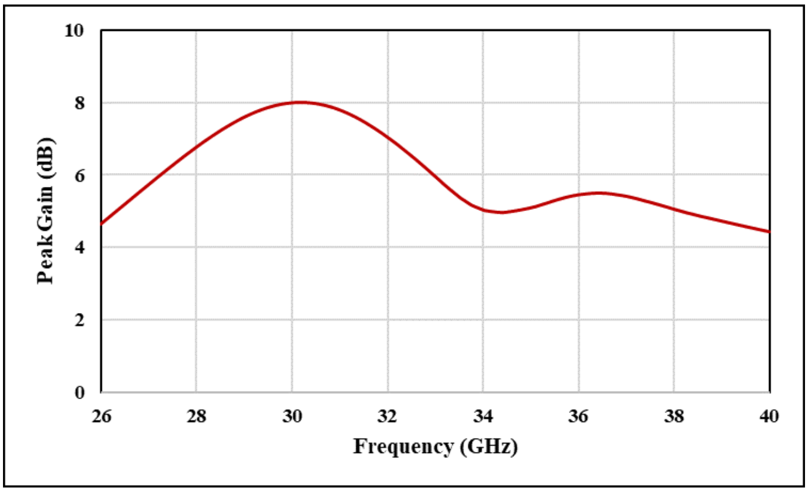

Figure 4.4: Peak gain plot of first design

This design is the basic design, in which compactness of the antenna is focused, and in all the further improvement in the design, in order to get the dual band with specific frequency, the compactness and size of the antenna is maintained intact. The objective of achieving the second band with the same structure leads to the second design.

4.4 Second Design with Rectangular Split Ring Slot

In this step of design flow, a rectangular split ring slot is presented on the radiating patch of the antenna, and the design is illustrated in figure 4.5. The primary aim of this slot is to obtain the resonance at higher side of frequency. This structure help in shifting the resonating frequency to higher side [98]. The position and dimension of the slot is optimized to get the desired resonance at exact frequency, and without any modification of the size of the patch, thus maintaining the compactness of the designed antenna.

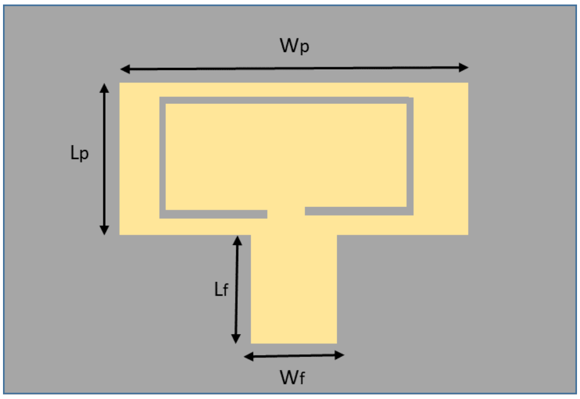

Figure 4.5: Layout of second design of mm-wave antenna

4.4.1 Results of Reflection Coefficient of Second design

The introduction of the first rectangular split ring slot results in the desired resonance at 36 GHz of frequency. Figure 4.6 show the simulated value of Reflection coefficients (S11) this design. The proposed antenna shows a very high value of reflection coefficient of -40 dB at 36 GHz of frequency. The antenna is resonating from 35 GHz to 37.4 GHz of frequency with a bandwidth of 2.4 GHz.

Both of the antenna designs, i.e. first design (plane patch antenna) and second design (patch antenna with one resonating slot), are showing the almost bandwidth of 2.4 GHz. These two designs would be useful for a high bandwidth single resonance antenna.

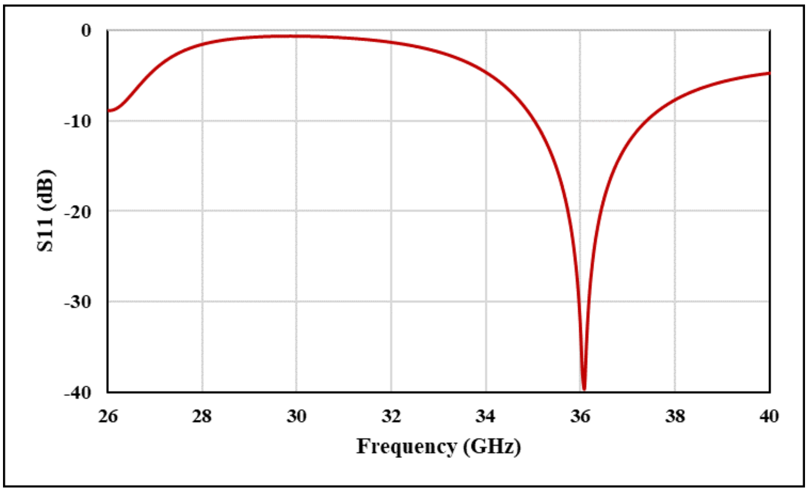

Figure 4.6: Reflection coefficient plot of second design

4.4.2 Results of Peak Gain of Second Design

A plot of peak gain along with the frequency is presented in Figure 4.7. At the frequency of 36 GHz, the value of peak gain is 5.5 dB. The antenna exhibits a high peak gain in excess of 4 dB in the entire zone of frequency ranging from 34 GHz to 40 GHz.

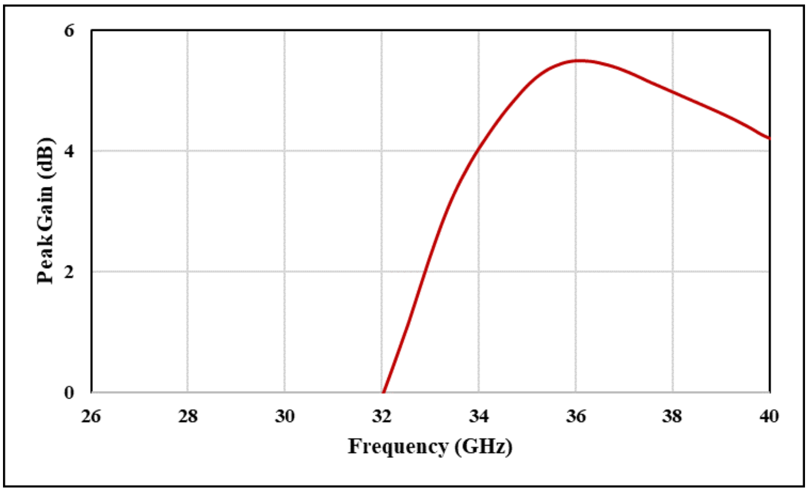

Figure 4.7: Peak gain plot of second design

This design is the results in the second band, which is at the higher frequency, without compromises the basic parameter of the antenna structure. In order to get the dual band with specific frequency, the third design is incorporated.

4.5 Third Design of mm Wave Antenna with Two Concentric Split Ring Slots

In this design step, another split ring slot, concentric with the previous one, is carved on the radiating patch of the microstrip antenna. The dual concentric split ring structure is useful in getting the dual band [99]. This design of the antenna, having the configuration of two concentric rectangular split ring slots on the patch, is illustrated in figure 4.8. The concentric double split ring slot design brings one more band near to 28 GHz with good performance. So, finally the two concentric slot provides the two desired resonating band.

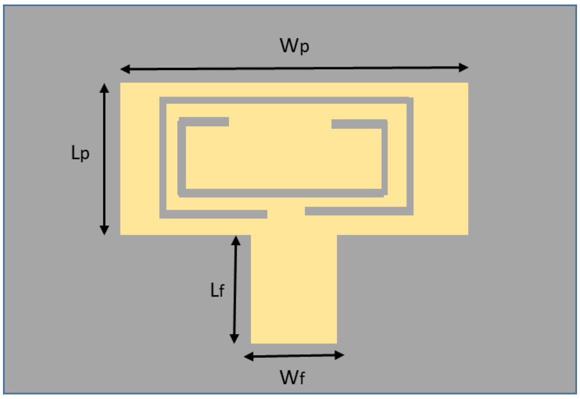

Figure 4.8: Layout of third design of mm-wave Antenna

4.5.1 Results of Reflection Coefficients of Third Design

The introduction of the second concentric slot results in getting the dual resonance at 27.6 GHz and 36.2 GHz of frequency. Figure 4.9 shows the simulated value of Reflection coefficients of this design. The proposed antenna shows a reflection coefficient of -19.5 dB at 27.5 GHz of frequency and -22 dB at 36.3 GHz of frequency respectively. This plot of reflection coefficient validates the design of dual resonating antenna. The reflection coefficients at the two peaks (27.6 GHz and 36.3 GHz) are almost same and this indicates the working of the antenna with same power at these two bands. The first band, centered at 27.6 GHz of frequency, has a bandwidth of 900 MHz and the second band centered at 36.3 GHz of frequency carries more bandwidth of the value 2 GHz.

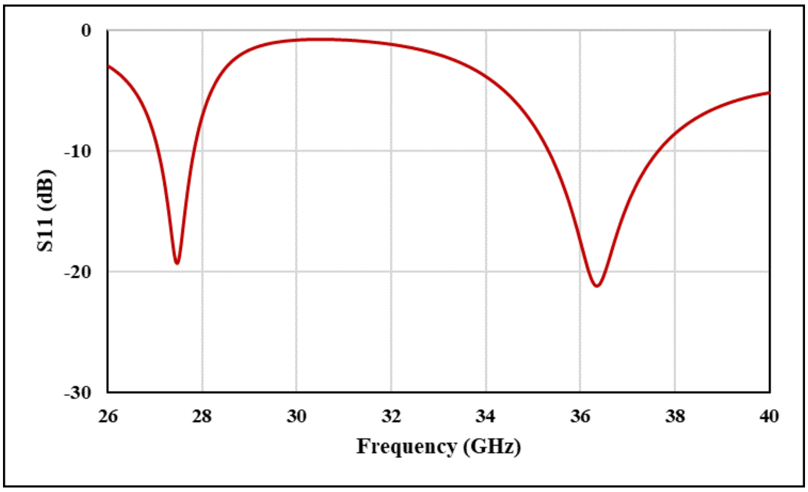

Figure 4.9: Reflection coefficient plot of third design

4.5.2 Results of Peak Gain of Third Design

A plot of peak gain along with the frequency is presented in Figure 4.10. The antenna exhibits a high peak gain in excess of 4 dB in the entire zone of frequency ranging from 26 GHz to 28.2 GHz and 34.2 GHz to 39.8 GHz of frequency. The maximum values of peak gain obtained are 7.6 dB at 27.6 GHz and 6 dB at 36.2 GHz of frequency.

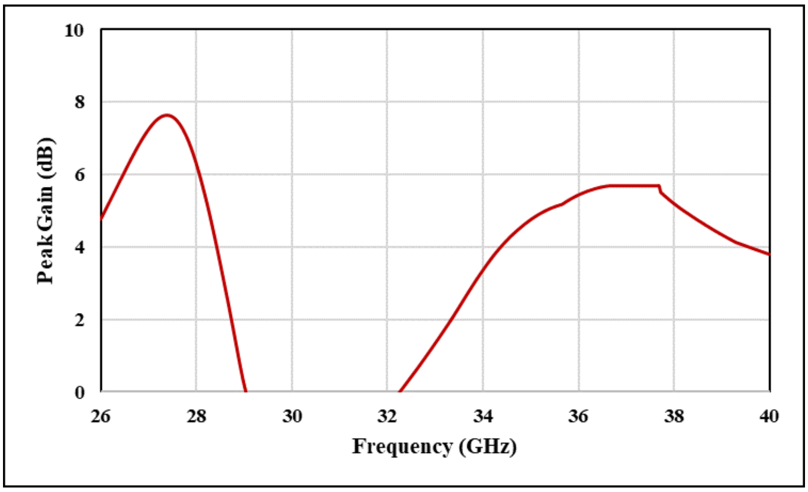

Figure 4.10: Peak gain plot of third design

However, this design produces dual bands with good performance in terms of reflection coefficient and gain, but the resonating frequency of these two band are not falling at the specific proposed frequency by DoT. This leads to the next design.

4.6 Fourth Design of mm Wave Antenna with Double Ring Slots and One Plane Slot

In this design process, a plane small slot of size 1 mm is placed at the inner region of double concentric split ring structure. The simulated diagram is shown in figure 4.11. The aim of this design is to increase the reflection coefficient.

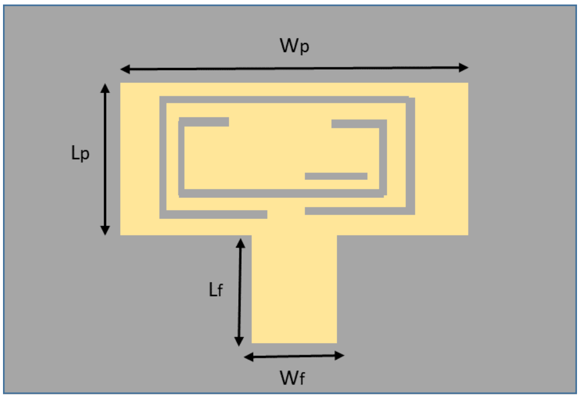

Figure 4.11: Layout of fourth design of mmWave Antenna

4.6.1 Results of Reflection Coefficients of Fourth Design

The introduction of the a plane rectangular slot above the second concentric slot results in getting the dual resonance at 27.6 GHz and 36.2 GHz of frequency. Figures 4.12 shows the simulated value of reflection coefficients with respect to frequency of this design. Here, a very high reflection coefficient of the value of -39.6 dB is achieved at 19.5 dB at 27.5 GHz of frequency and -22 dB at 36.3 GHz of frequency respectively. The inclusion of plane slot increases the reflection coefficient of the first band only. The first band, centered at 27.5 GHz of frequency, has a bandwidth of 600 MHz ,and the second band centered at 36.3 GHz of frequency carries more bandwidth of the value 2 GHz.

4.6.2 Results of Voltage Standing Wave Ratio of Fourth Design

The value of VSWR with respect to frequency is plotted and shown in figure 4.13. The value of VSWR is 1.02 at 27.5 GHz of frequency and 1.21 at 36.3 GHz of frequency. So,

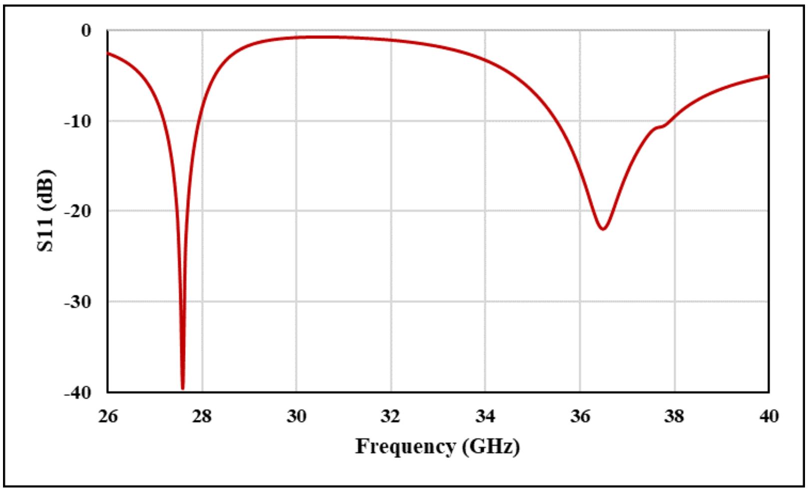

Figure 4.12: Reflection coefficient plot of fourth design

in both the bands, a very good value of VSWR is achieved.

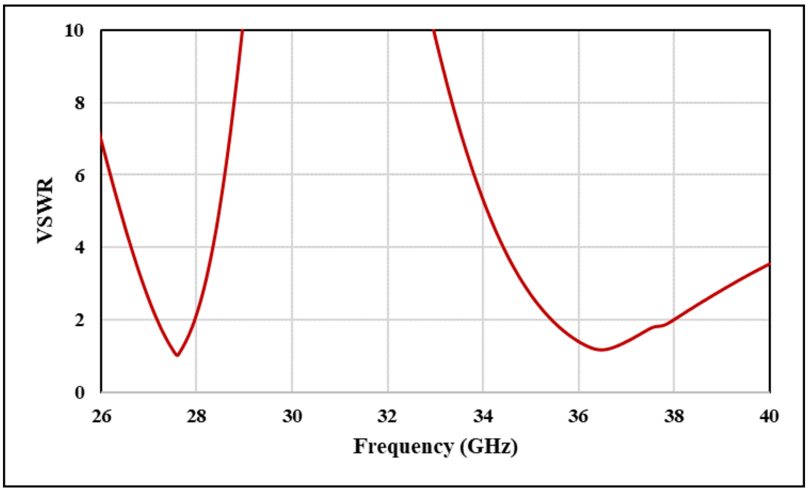

Figure 4.13: VSWR plot of fourth design

4.6.3 Results of Peak Gain of Fourth Design

A plot of peak gain along with the frequency is presented in figure 4.14. The antenna exhibits a high peak gain in excess of 6 dB in the entire zone of frequency ranging from 26 GHz to 28.2 GHz and 34.2 GHz to 39.8 GHz of frequency. The maximum value of peak gain obtained are 7.8 dB at 27.6 GHz and 6 dB at 36.2 GHz of frequency.

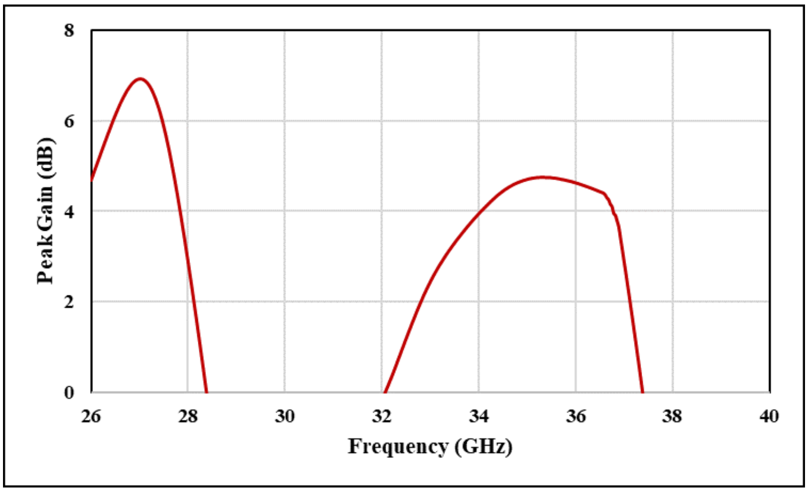

Figure 4.14: Peak gain plot of fourth design

This design results in bring the better performance in reflection coefficient, gain and desired bandwidth, but the second band lacks in achieving good reflection coefficient. Further improvement is required in this fourth design of mmWave antenna, for better impedance matching at both bands and exact specified resonating frequency. This propels to the final design of the antenna.

4.7 Final Design of mmWave Antenna

In the electromagnetic culture, substrate integrated guided slot technology has received more and more recognition for its versatility in the realization of microwave circuits in recent years. The characteristics of the distribution and dissipation of these guided slots are closer to that of rectangular wave guide, and these slots use those skills. In addition, integrated wave guided slot structure are assembled utilizing traditional printed circuit board technologies, making them easy to create and seamlessly combine with microstrip feedline in microstrip antenna design.

All the previous two design exhibits the dual band in the mmWave region, but the resonance frequency is not at the exact specified frequency, 28 GHz and 36 GHz, as proposed by international agencies and Department of Telecommunication in India. Hence, in order to get the exact frequency, the final structure of the designed antenna is completed with the introduction of two guided planer slot at the junction of feed-line and patch. These two symmetric slots are carved on the microstrip feed-line. These slot helps in improving the performance of the antenna by guiding the signals to the radiating patch, and it result in better impedance matching at both the resonances. It is depicted by the results obtained on various antenna parameters. The structure of the final proposed design of the antenna is illustrated in figure 4.15, whereas different values of antenna parameters are tabulated in table 4.2.

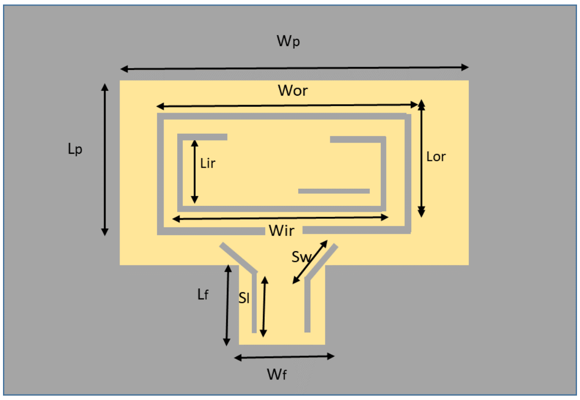

Figure 4.15: Layout of final design of mmWave antenna

Parameters	**Values (in mm)**
Substrate Height (h)	1.57
Patch Length (L_p)	2.7
Patch Width (W_p)	4.7
Feedline Length (L_f)	1.35
Feedline Width (W_f)	1.1
Substrate Length (L_s)	5.5
Substrate Width (W_s)	7.5
Width of outer ring slot $(W_o r)$	3.9
Length of outer ring slot $(L_o r)$	1.8
Width of inner ring slot $(W_i r)$	3.1
Length of inner ring slot $(L_i r)$	1.1
Width of wave guided slot (S_w)	0.5
Length of wave guided slot (S_l)	1

Table 4.2: Parameter of final designed mmWave antenna

4.7.1 Results of Reflection Coefficient of Final Designed Antenna

The introduction of the guided slot structure results in perfect resonance at 28 GHz and 36 GHz of frequency with adequate bandwidth. Figures 4.16 shows the simulated value of reflection coefficients with respect to frequency. In this final design, a very high reflection coefficient of the value of -29.8 dB is achieved at 28 GHz of frequency and -19 dB at 36 GHz of frequency respectively. This structure gives a perfect resonance at 28 GHz and 36 GHz of frequency. It helps in achieving the specified dual band mm-wave antenna. The first band, centered at 28 GHz of frequency, has a bandwidth of 1000 MHz, and the second band centered at 36GHz of frequency carries more bandwidth of the value 1200 MHz.

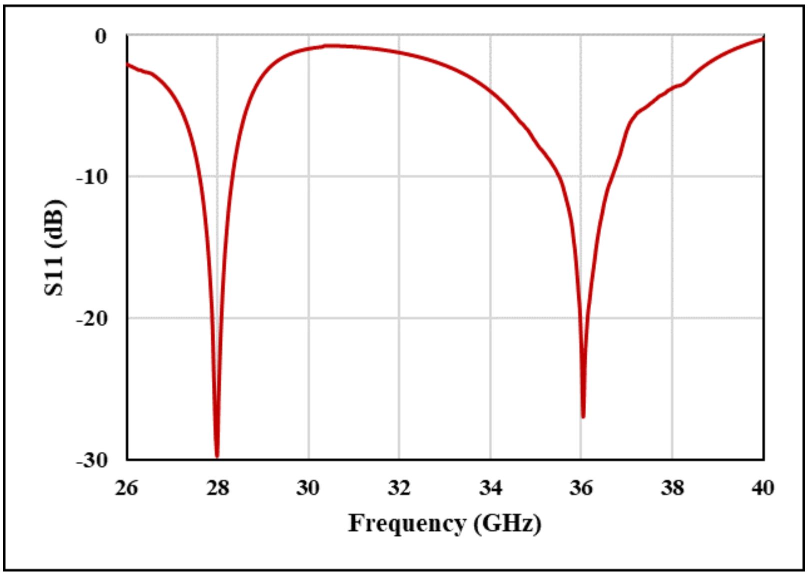

Figure 4.16: Reflection coefficient plot of final designed antenna

4.7.2 Results of Voltage Standing Wave Ratio of Final Designed Antenna

The value of VSWR with respect to frequency is plotted and shown in figure 4.17. The value of VSWR is only 0.6 at 28 GHz and 1.2 at 36 GHz of frequency. So in both the bands a very good value of VSWR, lower than 2, is achieved. This indicates a good radiation from the antenna with perfect matching and minimum loss.

4.7.3 Results of Peak Gain of Final Designed Antenna

A plot of peak gain along with the frequency is presented in Figure 4.18. The antenna exhibits a high peak gain in excess of 7 dB in the entire zone of frequency ranging from 26

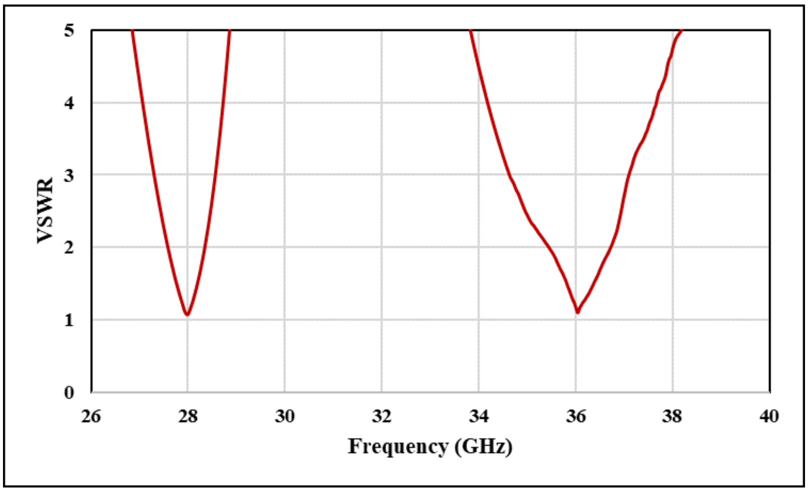

Figure 4.17: VSWR plot of final design

GHz to 28.2 GHz and 34.2 GHz to 39.8 GHz of frequency. The maximum values of peak gain obtained are 7.8 dB at 28 GHz and 5.6 dB at 36 GHz of frequency.

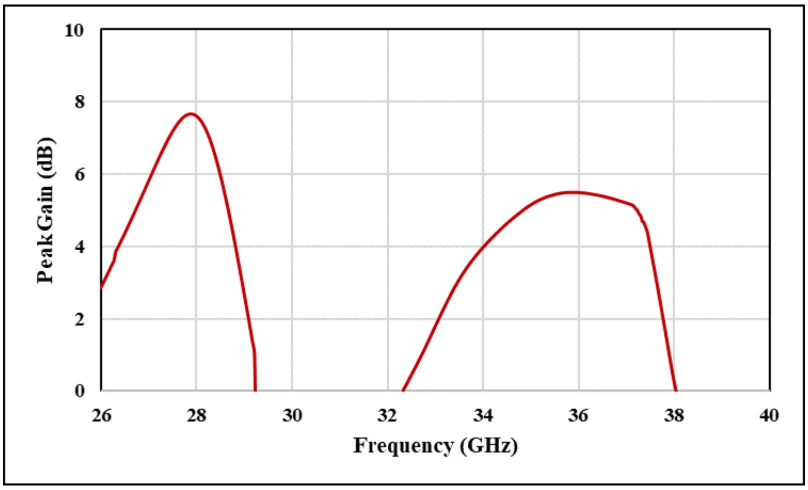

Figure 4.18: Peak gain plot of the final designed antenna

4.8 Fabrication, Measurement and Validation of Results

The final antenna is fabricated using RT Duroid (Rogers 5880) as dielectric substrate, having a dielectric constant of 2.2 and the height of the substrate is 1.57 mm. In the fabrication process, a photographic film of the antenna is carved out initially and then it is glued on the substrate. The radiating patch and the ground plane of the substrate is copper cladded. In the next stage, the antenna is etched out and finally a computerized mechanical etching process ensures the fabrication of antenna. In this process necessary care was taken to align the ground slit exact below the stub matched transmission line. The prototype of the final fabricated antenna is illustrated in figure 4.19.

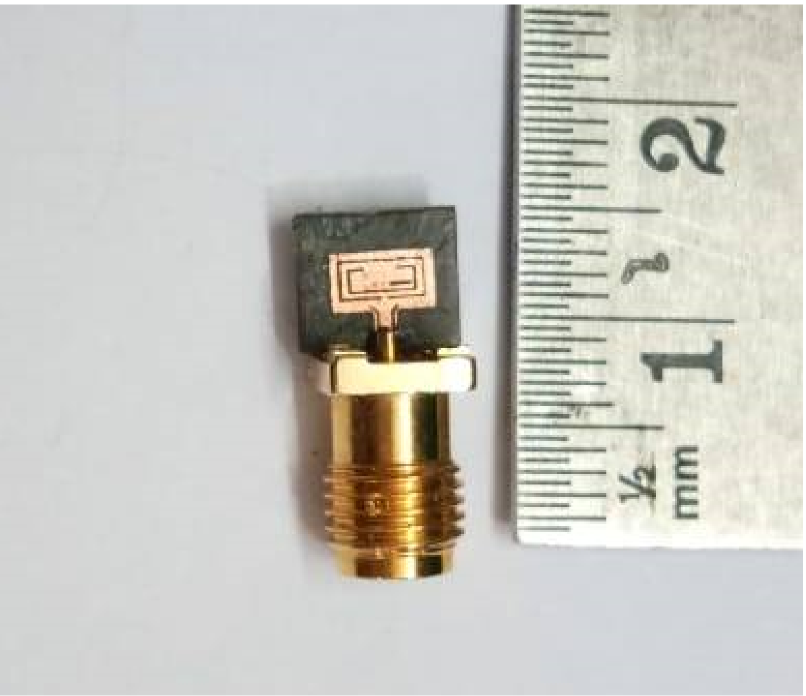

Figure 4.19: Photograph of the final proposed designed antenna

The results (reflection coefficient and VSWR) of the fabricated antenna is measured using VNA (Vector Network Analyzer) and its results are validated by comparing with the results of the simulated results. The gain and the radiation are measured in the anechoic chamber. The fabrication and measurement processes are completed at SAMMER.

4.8.1 Measurement Results of Reflection Coefficient of Final Designed Antenna

The parameters of the fabricated final antenna is measured using a Vector Network Analyzer (VNA). The measured values of the reflection coefficient, having two resonance, one at 28 GHz with the value of -27 dB and another at 36 GHz with -24 dB, is closely matched with that of the simulated results. The measured and simulated results, of the reflection coefficient, of the final design antenna, is plotted and it is shown in figure 4.20.

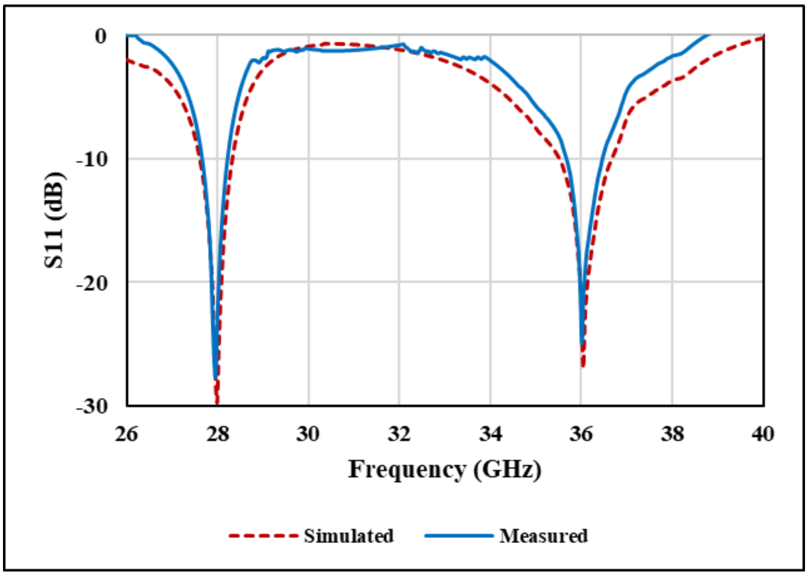

Figure 4.20: Comparison of the reflection coefficient of simulated and measured values of final antenna

4.8.2 Measurement Results of Voltage Standing Wave Ratio of Final Designed Antenna

The measured value of Voltage Standing Wave Ratio (VSWR) is also plotted in figure 4.21 along with simulated value of the final design antenna. The plot depicts the two clear resonating bands with a small deviation from the simulated results. This shows a good matching between the simulation and measurement work. The vertical axis (value of VSWR) is limited from 0 to 5 in order to get have a clear view of the appropriate variation of VSWR with frequency in the plotted figure.

The values of measured and simulated VSWR at 28 GHz are 1.14 and 1.09 respectively, whereas the values of measured and simulated VSWR at 36 GHz are 1.21 and 1.19 respectively. The range of VSWR is in 1:2 value and this validate the design.

In summary, both the reflection coefficient plot (figure 4.20) and VSWR plot (figure 4.21) indicates the close resemblance of the measured result with the simulated result of the design antenna.

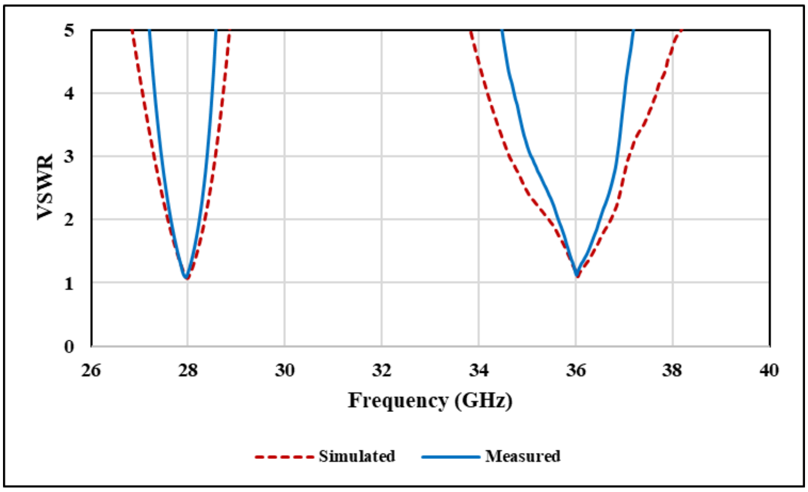

Figure 4.21: Comparison of the VSWR of simulated and measured values of final antenna

4.8.3 Measurement Results of Gain of Final Designed Antenna

The gain of the simulated antenna is measured at anechoic chamber. The plot of gain of both the simulated work and measured is plotted in figure 4.22. The measured antenna shows a gain of 6.3 dB at 28 GHz of frequency and 4.6 dB at 36 GHz of frequency. Therefore, in both of these two bands a high value of gain is achieved.

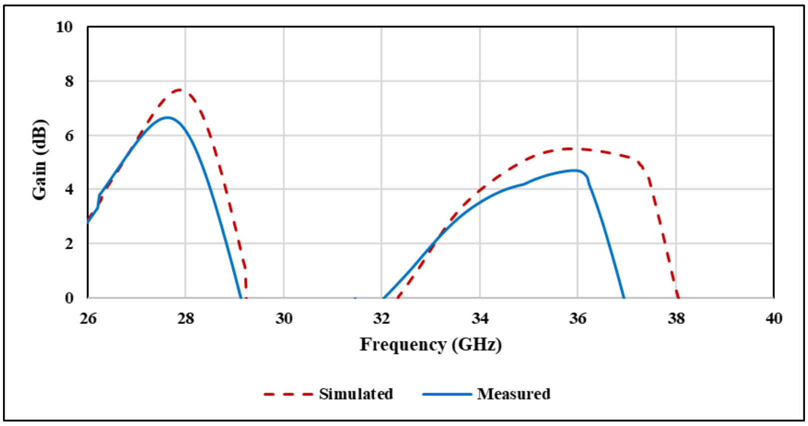

Figure 4.22: Comparison of the gain of simulated and measured values of final antenna

The matching between the simulated and experimental results validate the design of the antenna for gain.

4.8.4 Measurement Results of Radiation Pattern of Final Designed Antenna

The radiation pattern reflects the sensitivity of the antenna in different ways, so the antenna can be positioned in the optimum direction to ensure the appropriate performance. Polar diagrams are used to illustrate the reaction of antennas. Typically, the radiation pattern of an antenna is represented by a two dimensional graph.

The radiation appearances of the antenna for both plane (E-Plane and H-Plane) for the two bands are measured and plotted. The radiation, at both 28 GHz and 36 GHz of frequency, are measured in the anechoic chamber. The measurement set up for radiation pattern for millimeter wave antennas is same as that of sub 6 GHz band antenna discussed in the previous chapter. In the measurement setup, in the anechoic chamber, the antenna under test is placed on a turn table and connected to one port of the analyzer for reading. A wideband horn antenna, taken as reference transmitter, is connected to the other port of the analyzer. The turn table is controlled by positional controller and the number of reading is set accordingly.

The radiation pattern at two desired frequency viz 28 GHz, and 36 GHz are measured and the values are plotted, in 2-dimensional, along with simulated values for the verification.

The E-plane and H- plane plot for 28 GHz of frequency (both measured and simulated) is shown in figure 4.23 and 4.24 respectively. Both of the radiation plot demonstrate that the measured results are in accordance with the simulated design work. In the E-plane, maximum radiation intensity is towards the principle lobe of the antenna, and the back lobe is almost null. This shows the directive nature of the radiation. The measurement of H-plane results is also similar to the simulation result. The main lobe is dominating with almost no presence of back lobe radiation. Only in the measured result, the radiation intensity on the left side is lower than that of the simulated design work.

The E-plane and H- plane plot for 36 GHz of frequency (both measured and simulated)

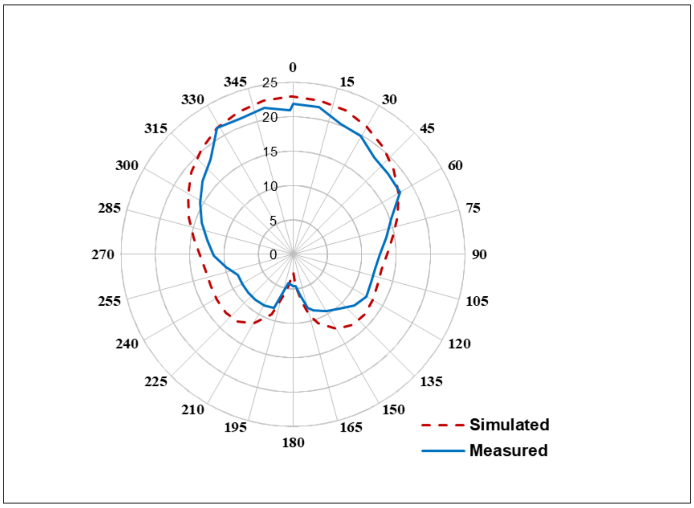

Figure 4.23: E-plane plot for 28 GHz

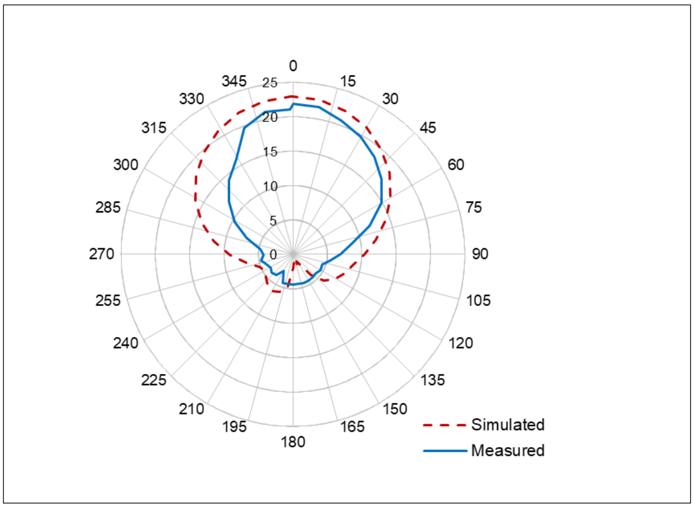

Figure 4.24: H-plane plot for 28 GHz

is shown in figure 4.25 and 4.26 respectively. In this frequency band, the radiation plot reveals that the measured results are in agreement with the simulated design work. In the E-plane, the antenna depicts the maximum radiation intensity in its principle lobe, and the back lobe is very little less than 2 dB. The measurement of H-plane results is also of same pattern as that of the simulation result. The main lobe is the dominating one and exhibiting the maximum radiation. Both of the E-plan and H-plan plot discloses the directive nature of the radiation.

The proposed antenna shows a symmetric radiation pattern with more than 14 dB at various resonance frequencies, at its prime direction, in both E-plane and H-plane.

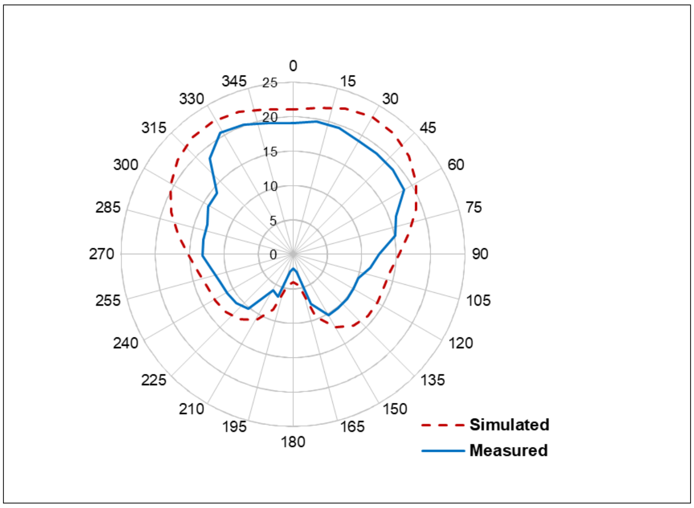

Figure 4.25: E-plane plot for 36 GHz

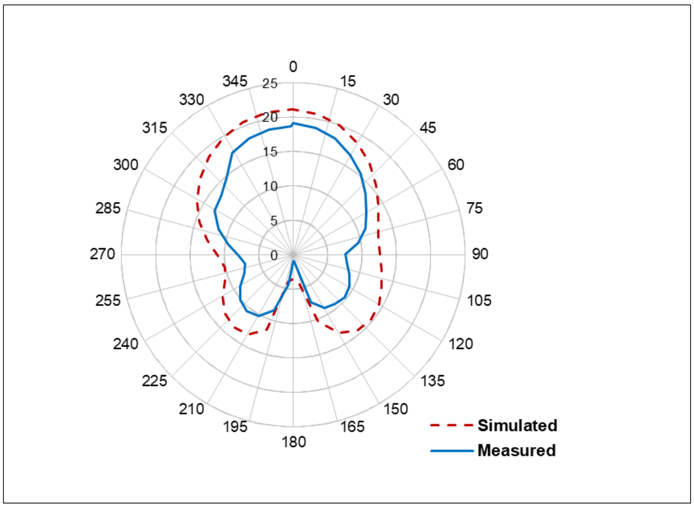

Figure 4.26: H-plane plot for 36 GHz

With these viable performances, the design antenna assertions its efficient application in mmWave region of the 5G technology.

4.9 Summary of Results

Table 4.3 below summarized the simulated and measured results of the proposed antenna for the two resonating bands in mmWave spectrum range.

Resonance Frequency	**Parameter**	**Simulated**	**Measured**
First band at 28 GHz	Reflection coefficient	-29 dB	-27 dB
	VSWR	1.14	1.09
	Gain	7.8 dB	6.3 dB
	Bandwidth	1000 MHz	800 MHz
Second band at 36 GHz	Reflection coefficient	-26 dB	-24 dB
	VSWR	1.21	1.19
	Gain	5.6 dB	4.6 dB
	Bandwidth	1200 MHz	1000 MHz

Table 4.3: Summary of the simulated and measured results of the final design antenna

4.10 Comparison of Results with Existing Literature

In this section, a comparison of the converged design is done with four current work done by other researchers and summarized in Table 4.4. Our work is exactly in accordance with the frequency proposed by Government of India for 5G technology in mmWave region.

References	**Resonating Frequency**	Bandwidth	**S-parameter**	**Gain**	**Dimensions** (in mm^3)
[100]	28 GHz	4.6 GHz	-45 dB	Not available	5 × 5 × 1.6
[101]	28 GHz 39 GHz	9.3 GHz 4.1 GHz	-32 dB -27 dB	2.3 dB 4.8 dB	4×9.45×0.26
[102]	17 GHz 28.6 GHz 32.5 GHz	600 MHz 480 MHz 860 MHz	-19 dB -15 dB -22 dB	-0.2 dB 1.1 dB 2.96 dB	4.4×4.2×0.8
Designed Antenna	28 GHz 36 GHz	800 MHz 1000 MHz	-29 dB -24 dB	7.8 dB 5.6 dB	4.7 × 4.05 × 1.57

Table 4.4: Comparison of the designed antenna with existing literature.

4.11 Chapter Summary

This chapter presented the design of a multi-band (two precise resonating frequency) 5G antenna with concentric split ring slotted structure. The proposed antenna, compact in size, exhibits two bands precisely at 28 GHz and 36 GHz of frequency in the mmWwave region of the 5G frequency as proposed by international agencies and Department of Telecommunication in India. The bandwidth of the two bands are 800 MHz and 1000 MHz respectively. The reflection coefficient at the two bands reveals an improved impedance matching in excess of -20 dB.

The gain response of the proposed antenna is more than 5 dB in both resonance frequencies. The radiation pattern shows symmetrical and directive in nature with a better result in excess of 15 dB. The radiation pattern also clearly shows the directive nature. The validation of the design with the measured results assertions its design, compactness of the antenna dimension positioned this for an efficient application in for 5G futuristic communication and with all these viable performances.

Chapter 5

CONCLUSION AND FUTURE SCOPE

In this thesis work, two types of multi-resonance antennae designed are proposed with their different performance and specific spectrum application to be used for proposed fifth generation cellular network frequency bands. We suggested two antennas in conjunction with the specification laid down by Department of Telecommunication, Govt of India. One of the designed antenna is for the application in sub 6 GHz and another is in mmWave.

With advancement of the new technologies, which are, promulgating new services and applications, 5G cellular technology, being regarded as futuristic communication of the new era, are now being intended to cope up with new applications and services. The primitive fifth-generation research began in 2012, further all standards and processes have been placed for the new generation mobile networks in 2017-18. Numerous innovations were implemented to release for futuristic fifth-generation networks. They are either the advanced augmented forms of the technologies/ theory of previous legacy generations or recent ones.

Recently, modern antennas with good impedance bandwidth, high gain and notable radiation patterns are needed particularly at higher frequencies, due to the enormous increase in the number of wireless communication systems and devices, and consequently a significant increase in demand for new and high-quality applications.

5.1 Implication of Sub 6 GHz Design Antenna

The first antenna in sub 6 GHz is a multi resonance antenna depicting 3 bands. In this design work, inverted-F slot in addition with fractal slot structure on the antenna radiating layer is analyzed. For multiple frequency resonance in the sub 6 GHz band, the fractal antenna structure has been chosen. In order to deliver efficient multiband properties, the proposed antenna is implemented with symmetrical fractal at the boundary and inverted slots at the aperture. A stub-matched technique is implemented with offset feeding to enhance the impedance matching at multiband properties. Using a slotted Split ring structure, the efficiency of the proposed single layer antenna was further improved. In summary, the features achieved from this design antenna are summarized as:

- The antenna operates in three multi resonating bands at 2.1 GHz, 3.3 GHz, and 4.1 GHz of frequency.
- These three resonating frequency are strictly in accordance with the frequency bands regulated by the department of telecommunication, Government of India.
- The three bands are in LTE band, n78 and n77 band of 5G technology.
- The antenna exhibits an impedance bandwidth of 200 MHz at each of the three bands.
- The reflection coefficient is in excess of -18 dB
- The gain of the antenna is ranging from a minimum value of 4.1 dB to a maximum value of 5.4 dB with notable radiation pattern.

5.2 Implication of mmWave Design Antenna

The second design proposed antenna is a dual band antenna in mm Wave region. It comprises of a dual concentric split ring slots and wave guided slots structure. This split ring structure is used for getting dual band resonance and parameters of the design antenna are enhanced by guided wave slot structure. The key problem for antennas in the mmWave frequency range is the acceptable antenna size thus maintaining sharp resonance peaks, return losses, good gain and radiation quality. All these has been quiet achieved with these salient features, and summarized as:

- The two band of resonance are achieved by this design.
- The two resonating bands are exactly at 28 GHz and 36 GHz of frequency.
- The bandwidth achieved at the two bands are 800 MHz and 1 GHZ respectively.
- The bands are n257 and n260 band of 5G technology.
- This antenna exhibits a good reflection coefficient in excess of 20 dB at both the resonances.
- The gain response is more than 6 dB in first band and 4 dB in second band with notable radiation pattern.
- The size of the antenna is merely 4.7 mm by 4 mm

The close proximity of all the active and passive parameters in both the design validates the design of the antenna. With these viable performances the proposed antenna assertions its meaningful applications in futuristic communication.

5.3 Suggestions for Future Scope of Work

The proposed work has opened for the following interesting points for further investigations:

1. More multi resonance antenna can be designed with good dielectric characteristics.
2. Miniaturization of the antenna can be an optimization goal.
3. Multi-channel Antennas can be designed using optimization techniques.
4. Antennas for higher bands of the mmWave region can be designed using optimization techniques for indoor and outdoor applications.
5. Unified antenna can be designed for new generation devices for 5G applications.

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List of Publications

1. Ranjan Mishra, Rajeev Dandotia, Raj Gaurav Mishra, Piyush Kuchhal, Rupendra Kumar Pachauri, (2020) "SRR Slotted Multiband Antenna in Sub 6-GHz for Futuristic Communication" EAI Endorsed Transactions on Energy Web, August, 2020. [**Scopus Indexed**]

2. Rajeev Dandotia, Ranjan Mishra, S M. Bhaskar, Raj Gaurav Mishra, Piyush Kuchhal, (2019) "SSR Based Slotted Patch Antenna with Integrated Wave Guiding structure for 5G Application" International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-9 Issue-2, December, 2019. [**Scopus Indexed**]

3. Rajeev Dandotia, Ranjan Mishra, S M. Bhaskar, Raj Gaurav Mishra, Piyush Kuchhal, (2019) "Analysis of Impedance Matching and Solution of Differential Partial Equation of Microstrip Antenna using Transmission Line Model" International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249-8958, Volume-8 Issue-5, June 2019. [**Scopus Indexed**]

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SYNOPSIS

- Currently working as **Director** (level 13) in National Technical Research Organization, block-III, old JNU campus, New Delhi.
- Associated with NTRO, Govt. of India since 2006.
- Total experience of about 14+ years in government sector, technological research and industry exposure. During 14 years, various position in project acquisition, management & operations, administrative & core management position hold in organization.
- Bachelor of Engineering (BE) in Electronic from Maharana Pratap College of Technology, Gwalior (affiliated to RGPV Bhopal) in 2001.
- Successfully handled a number of projects in terrestrial communication, cyber domain and phase array radar system.
- Excellent communication, interpersonal & analytical skills with the ability to grasp new concepts & utilize the same in a productive manner.
- Participated inter departmental committees and various forum for policy matters.
- Keys role in strategic acquisition of projects of national importance.

TRAINING/ COURSES

- Training in ALT Centre, DoT, Ghaziabad on various telecom industry aspects.
- Training on national security issue in MHA.
- Course on terrestrial communication system on operational & functional aspects, New Delhi
- Training on language identification.

- Certification in project management by International Institute of Projects & Program Management (i2P2M)
- Program on drafting contracts & Methods of negotiation in Institute of Secretariate Training And Management.
- Management development program on organizational resources and processes in Indian Institute of Foreign Trade, New Delhi
- Continuing Education Program on Dielectric Resonance Antenna- analysis & design in IIT Kharagpur

FOREIGN TRAINING

- Training on Radio Communication intelligence at Germany.

FOREIGN ASSIGNMENT

- Team Leader for finalizing MoU for Strengthen and establishment of the indigenous research facility signal analysis and communication protocol development.
- Conducted factory acceptance and attended international seminar and conferences.

AWARDS & APPRECIATIONS

(i) **Awards:**

Two institutional awards have been bestowed for outstanding and consistence work in respective field

- Vishwakrma awards for outstanding performance in 2017.
- Team of quarter Award – 2018

(ii) Commendations

- Commendation certificate best project execution 2019
- Commendation certificate for outstanding in 2017
- Commendation certification for outstanding in 2016
- Commendation certification for outstanding in 2015
- Appreciation letter for outstanding operational contribution.
- Departmental commendation certificate for excellent work proficiency

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December, 2020

UPES

PLAGIARISM CERTIFICATE

1. We **Dr Ranjan Mishra** (Internal Supervisor/ Guide), **Dr SM Bhaskar** (External Supervisor/ Guide) certify that the Thesis titled **"Design of Multi-Resonance Antenna for Future Communication"** submitted by Scholar Mr Rajeev Dandotia having SAP ID 500024917 has been run through a Plagiarism Check Software and the Plagiarism Percentage is reported to be 2% similarity index, 1% Internet Sources and 3% publications.

2. Plagiarism Report generated by the Plagiarism Software is attached.

Ranjan Mishra

Signature of the Internal Supervisor

Signature of External Supervisor

Dandotia

Signature of the Scholar

Thesis

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1	"Handbook of Antenna Technologies", Springer Nature, 2016 Publication	2%
2	"SSR Based Slotted Patch Antenna with Integrated Wave Guiding structure for 5G Application", International Journal of Engineering and Advanced Technology, 2019 Publication	1%

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