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BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

DESIGN AND SIMULATION OF A DUALBAND ANTENNA OPERATED AT FR-1 AND FR-2 RANGE FOR 5G-IoT APPLICATIONS

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Candidate Declaration

It is declared that the work presented in this thesis has not been submitted elsewhere for the award of any degree or diploma and does not contain any unlawful statement.

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Dedication

This thesis is dedicated to our parents, teachers, and unknown researchers whose research and innovation have been forgotten.

Acknowledgments

In the name of Allah, the Entirely Merciful, the Especially Merciful. All praise and glory are to Allah (SWT) for blessing us with opportunities to abound and showing us His mercy and guidance throughout life. And may Allah's peace and blessings be upon the Prophet Muhammad (PBUH), who has been a source of inspiration and guidance in our lives. I express my sincere gratitude and indebtedness to our thesis supervisor and Head of the Department of Electronic and Telecommunication Engineering, IIUC Engr. Syed Zahidur Rashid, Assistant Professor, for his initiative in this field of research, valuable guidance, and encouragement throughout the research. I also thank him for providing me with the best facilities in the department and for his timely suggestions. I am also thankful to Engr. Abdul Gafur, Associate Professor and Convener of the Thesis Committee of 2022, for his dedication and sacrifice. I also want to thank our entire teacher team for putting forth their best effort throughout the entire academic year. And I remember my parents for their support in my lives until now. And I also express gratitude to my friends, senior graduates, and well-wishers for being directly or indirectly involved in completing this thesis work.

Abstract

IoT, or the Internet of Things, is a network of interconnected computing devices, digital and mechanical, with unique IDs and the capacity to transport data over a network without requiring human or computer intervention. The use of IoT devices is increasing day by day. The inclusion of 5G technology will make IoT devices even more responsive. As a result, much research has been done in which researchers suggest their design of a suitable antenna. However, wireless communication researchers have difficulty designing compact multiband antennas capable of simultaneously covering all of the new 5G radio frequencies. This thesis paper uncovers a dual-band antenna capable of covering the 5G radio frequencies concurrently. The antenna proposes has a dimension of $20\times10\times0.322$ mm^3 for sub-6GHz operation at 5GHz and 28GHz for mm wave operation. The substrate used is Rogers RT5880LZ, which has a thickness of 0.252 millimeters. The bandwidths at 5GHzand 28GHz are 701.5MHz and 4.672GHz, respectively, with a corresponding acquired gain of 1.866 dBi and 7.266 dBi. The proposed antenna has 92.34 percent efficiency at 5GHz and 95.84 percent efficiency at 28GHz. The proposed antenna was designed and tested using CST Microwave Studio 2018. The simulation results are good for mainstream 5G-RFID and mobile Internet of Things applications.

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List of Abbreviations

2D	Two Dimension
3D	Three Dimension
0G	Zero Generation
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AMTS	Advance Mobile Telephone System
FDMA	Frequency division multiple access
TDMA	Time division multiple access
CDMA	Code division multiple access
OFDMA	Orthogonal frequency division multiple access
SDMA	Spatial division multiple access
PDMA	Polarization division multiple accesses
WPAN	Wireless Personal area network
WSAN	Wireless Sensor Networks
WLAN	Wireless Local Area Network
Wi-Fi	Wireless Fidelity
WWAN	Wireless Wide-Area Network
FCC	Federal Communication Commission
GSM	Global System for Mobile communication
CST	Computer Simulator Technology
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
GPRS	General Packet Radio Service
EVDO	Evolution-Data Optimized
HSPA	High-Speed Packet Access
LTE	Long Term Evolution
NMT	Nordic Mobile Telephone
TACS	Total Access Communication System
GSM	Global System for Mobile Communications
ETSI	European Telecommunications Standards Institute
3GPP	Third Generation Partnership Project
PCS	personal communications services
ITU	International Telecommunication Union
IoT	Internet of Things
RAN	Radio Access Network
IEEE	Institute of Electrical and Electronic Engineers
WCDMA	Wideband Code Division Multiple Access
NTT	Nippon Telegraph & Telephone
EV-DO	Evolution-Data Optimized

OTT	One-Trip Time
RTT	Round-Trip Time
IMT	International Mobile Telecommunications
UE	User Equipment
FR	Frequency range
MIMO	Multiple input Multiple Output
LDPC	low-density parity-check codes
IIoT	Industrial Internet of Things
AI	Artificial Intelligence
IP	Internet Protocol
RFID	radio-frequency identification
MAC	Media Access Control
ISM	Industrial, Scientific, and Medical
EM	Electro Magnetic

List of Symbols

Hz	Hertz
KHz	Kilo Hertz
MHz	Mega Hertz
GHz	Giga Hertz
mm	Millimeter
cm	Centimeter
m	Meter
ε	Relative permittivity
L	Length
W	Width
C	Speed of light
dB	Decibel
λ	Lambda
Ω	Ohm
εr	Dielectric Constant

Organization of This Book

The book is divided into nine chapters. To understand the book clearly, we design the book this way. The organization of the chapter of this book is described below-

Chapter One: - Wireless Communication: A Brief Overview

This chapter provides the information we need to know to understand wireless communication. In the book, we discuss the history of wireless communication, the importance of wireless communication, wireless communication standards, wireless communications generation, and a comparison between the generation of wireless communication. Finally, we discuss the latest fifth generation and its specifications. Some important terms and concepts are described briefly in this chapter that will help us to understand the relevant basic knowledge and base history of this research work.

Chapter Two: - Internet of Things (IoT): A Massive Connection

This chapter discusses the IoT or the internet of things. We provide some vital information on IoT here. The information provided here will help to understand the base of IoT. Among them, some topics are understanding the IoT, history of IoT, Its working style, requirements, and protocol, 5G and IoT, and application of IoT.

Chapter Three: - Antenna and Propagation

This Chapter and its topic are directly connected to this research. This chapter discusses the antenna basics concept, working principles, different antenna types, and performance parameters.

Chapter Four: - Literature Review and Motivation

This chapter talked about this research study's literature review and motivation. The literature review or the research paper analyses done during this work are summarized in this chapter. In addition, this chapter included the motivation, aims & objectives, problem statement, and impact of this research on society and the environment.

Chapter Five: - Design and Simulation Tools

In this chapter, the tool used for this work mentioned. The importance of simulation in research and some information on the tool that used in this work provided here.

Chapter Six: - Methodology and Antenna Designing Steps

In here, the methodology of this research discussed and the steps and working procedure that we followed during the research is described .The antennas designing step and parameter also provided in this chapter.

Chapter Seven: - Antenna Simulation and Result Analysis

In this chapter, the result of the simulation discussed the parameter that consider to examine an antenna showed in here, and some of them are return loss, gain, VSWR etc. In addition, a comparison table presented to compare the proposed antenna with other work.

Chapter Eight: - Achievements and Future work

This is the final and last chapter of this book where the achievement of this thesis work is described also the limitation, and the future work mentioned in this chapter.

Chapter 1
Wireless Communication: A Brief Overview

1.1 INTRODUCTION

Wireless communication is data sharing between two or more sites without needing an electrical conductor, optical fiber, or another continuously directed channel. It includes a variety of fixed, mobile, and portable applications such as wireless networking, two-way radios, cellular phones, and personal digital assistants. The most widely utilized wireless technologies make use of radio waves. Radio waves can travel as little as a few meters for Bluetooth and as far as millions of kilometers for deep-space radio communications. Since Guglielmo Marconi first showed radio's capacity to offer continuous communication with ships crossing the English Channel, the ability to communicate with individuals on the go has grown dramatically. That was in 1897, and since then, people worldwide have joyfully embraced new wireless communications technologies and services. In particular, over the last ten years, the mobile radio communications sector has experienced orders of magnitude growth, driven by advancements in digital and RF circuit manufacturing, new large-scale circuit integration, and other downsizing technologies that reduce the size, cost, and reliability of portable radio equipment. The widespread implementation of inexpensive, user-friendly radio communication networks has been made possible by digital switching methods. Over the following years, these tendencies will accelerate even further.

1.2 HIGHLIGHTED HISTORY OF WIRELESS COMMUNICATION

In communications, "wireless" has had two distinct meanings. It was used for early radio transmitting and receiving technologies, such as wireless telegraphy, from 1890 to 1920. U.K. non-portable radios were called wireless sets until the 1960s. Uncertain - examine how the word was revived in the 1980s and 1990s to identify digital gadgets that connect without wires or cables. In the 2000s, mobile broadband, Wi-Fi, and Bluetooth became popular [1].

Early Chinese, Greek, and Roman civilizations' grasp of magnetic and electric properties and 17th- and 18th-century experimentation led to wireless communications. Here are some wireless communications milestones. Jean Baptiste Joseph Fourier derived Fourier's theorem in 1807. Hans Christian Orsted developed the electric current's electromagnetic field in 1820. Dominique Francois Jean Arago showed how a wire's current turned it magnetic. Andre-Marie Ampere conceived the electromagnetic telegraph and discovered electrodynamics. Michael Faraday anticipated electromagnetic waves and electromagnetic induction in 1831. Samuel Finley Breese Morse invented the Morse code in 1834. In 1847, Hermann Ludwig Ferdinand von Helmholtz suggested electrical oscillation. William Thomson (Lord Kelvin) calculated an oscillating circuit's period, damping, and intensity in 1853. Feddersen tested Helmholtz's 1847 tuned circuit's frequency. James Clerk Maxwell developed the electromagnetic theory of light and electromagnetic field equations in 1864. He condensed 20 equations into the four used today. Dr. Mahlon Loomis described and demonstrated a wireless communication device in 1866. Loomis demonstrated communication transmission across a 22-kilometer span. Amos Emerson Dolbear patented a wireless communication system in 1882 using an induction coil, microphone, telephone receiver, and battery. Nathan Stubblefield transferred audio information wirelessly. Irish physicist and chemist George Francis FitzGerald discovered a formula for loop antenna power in 1883. Heinrich Rudolf Hertz wrote Maxwell's equations in scalar form and eliminated aether in 1884. Thomas Edison patented a wireless electrostatic induction method in 1885. Heaviside originally established impedance in 1886. Hertz proved radio waves existed in 1888. Oliver Joseph Lodge developed sympathetic resonance in 1887. Hertz employed reflectors in 1888 to make, transmit, and receive 5 m to 50 cm electromagnetic waves. Hertz invented Radar. Heaviside produced vector versions of Maxwell's equations. Tesla and Ferrari separately invented two-phase rotating fields. Ernst Lecher found the link between frequency, wire length, propagation speed, and electrical constants. Lecher measured frequency using parallel wires in 1890. Tesla discovered that living tissue might become hotter when subjected to high-frequency currents. Sir Jagadis Chunder Bose invented waveguides, horn antennas, and more. He sent and received wireless signals. Marconi demonstrated radio across 18 miles of the English Channel to a tugboat in 1897. The Wireless Telegraph and Signal Company used Marconi's patents as the first wireless Company. Lord Rayleigh recommends studying E.M. wave propagation using dielectric-filled waveguides. Lodge patents antennas. Marconi made the first international radio communication from England to France in 1899. Tesla's 1900 electrical energy transmission patents were the first U.S. radio patents. Tesla first described Radar, which utilizes radio waves to locate an object. 1902: Fessenden invents Heterodyne receiver. Cornelius D. Ehret patented the transmission and reception of coded signals or voice (F.M.). Poulsen invented the CW transmitter. King Edward VII and President Theodore Roosevelt attended the dedication of the Marconi transmission station in South Wellfleet, Massachusetts. Sprague invented the printed circuit in 1904. W. Pickard patented a crystal detector that contacted silicon with a wire. It was the key component of early crystal radios. J. C. Bose patented point contact diodes, long used as detectors. Fleming suggested leveraging the diode's rectifying action to discover high-frequency oscillations. Fessenden invented superheterodyne in 1905. Lee de Forest patented the Omni range in 1906 using a revolving radio beam keyed to identify a 360-degree sector. In 1913, he invented the vacuum tube triode, a three-electrode valve vital to intercontinental telecommunications. Poulsen sent music 300 miles away with a 1 kW wireless arc transmitter and 200-foot antenna. Marconi and Braun shared the 1909 Nobel Prize in Physics for radIoTelegraphy and electric oscillations. Von Lieben and Eugen Riesz created a cascade amp in 1911. Hugo Gernsback introduced pulse radar by advocating for a pulsating polarized wave, as detected by an anoscope. 1911 - Engineers realized that the three-electrode vacuum tube could be used as a transmitter and oscillator. 1912: G.A. Campbell invents guided wave filters. Sinding and Larsen aired T.V. on three channels. In the U.S., IRE was founded. Walter Schottky discovered in 1914 the effect of electric field on thermionic emitter electron emission. Fleming discovered air refraction's involvement in electromagnetic wave transfer. Carl R. Englund devised the AM wave equation and sideband frequencies. Frequency modulation was recommended to accommodate more channels in available bandwidths. Schottky started work on the space-charge-grid tube and the Tetrode in 1915. The Tetrode used a screen grid to create efficient grid-to-anode amplification. Georges A. Beauvais and Leon M. Brillouin invented the R-C amplifier in 1916. F. Adcock patented open vertically spaced aerials for aviation direction finding. Armstrong produced the first superheterodyne radio receiver in 1918. Langmuir patented the feedback amplifier. Direction finding was one of England's most vital weapons during WWI; Bellini-Tosi aerials were erected along the beach to detect ship and aircraft transmissions. Louis Alan Hazeltine designed the neutrodyne circuit with controllable R.F. and neutralization. Marconi-Osram created U-5 twin-anode full-wave rectifier in 1919. Joseph Slepian patented a vacuum tube electron multiplier. Sir Robert Alexander Watson-Watt patented the radiolocation apparatus that became Radar. Purington invented the first all-electric frequency modulator in 1921. A.W. Hull's Magnetron oscillator offers 8 kW output and 69% efficiency at 30 kHz. E. H. Colpitt and O. B. Blackwell modulated audio frequencies with lower audio carrier frequencies for wired telecommunication. Butterworth authored a landmark work on proximity and skin effect in single-coil H.F. resistance. Walter Guiton Cady invented the piezoelectric (Quartz) oscillator in 1922. First BBC newscast. In 1923, the decibel (1/10th of a bel, named after A. G. Bell) was used to measure telephone cable loss. H. W. Nichols pioneered point-to-point communication using single-sideband transmission. Prince compared class A and class C amplifiers. Antoine Logie Barid patented the first T.V. Watson-radiolocation gives the radar operator target direction, distance, and velocity.

Watt's radio equipment utilized a cathode ray oscilloscope. Ralph Vinton Lyon Hartley showed the link between data rate and bandwidth. H. Flurschein patented radio car-warning devices. J.R. Carson applied Lorentz's reciprocity theory to E.M. fields and antenna terminals in 1924, proving that a receiver's energy absorption is proportional to its bandwidth. Watson-Watt improved the radiolocation device by displaying the target's direction, distance, and velocity on a cathode ray oscilloscope. Ralph Vinton Lyon Hartley showed that bandwidth is inversely linked to information transfer rate. Flurschein patented a vehicle-mounted radio warning system. J.R. Carson applied Lorentz's reciprocity theory to E.M. fields and antenna terminals in 1924. He showed that a receiver's energy absorption is proportional to its bandwidth. Espenschied invented the radio altimeter. Bell invented the mobile phone, originally used in NYC police cars. 1925 saw Geneva's first frequency-allocation meeting. Joseph Tykocinski-Tykociner established that a 3-to-6-m short wave could replace a full-size antenna's features. 1926: L.E. Lilienfield patents the Field-Effect Transistor. Hidetsugu Yagi and Shintaro Uda designed the Yagi antenna, a row of 20 undriven members and one active antenna. Huelsenbeck and Company patented C.W. radar for locating buried objects. 1927: R. V. Hartley creates the mathematical theory of communications. Harold Stephen Black devised the negative feedback amplifier. A. de Hass studied fading and developed a diversity receiver. Baird aired the first transatlantic T.V. broadcast in 1928. Nyquist wrote on telegraph signal transmission theory. He established guidelines for the noise-free receipt of telegraph signals conveyed through dispersive channels. C.S. Franklin patented coaxial cable as an antenna feeder in England. L. Cohen proposed employing resonant transmission lines for radio reception in 1929. AT&T/Bell Labs' H.A. Eiffel and L. Espenscheid invented coaxial cable for FDMA multi-channel phones. K. Okabe's slotted-anode magnetron advanced cm-waves (5.35 GHz). Hans Erich Hollmann devised the reflex klystron. W.H. Martin proposed the Decibel transmission device. H. Diamond and F. W. Dunmore created a radio beacon and receiver system in 1931. H. E. Hollmann built the first decimeter transmitter and receiver at the Heinrich Hertz Institute. The magnetron was his term. ITU was founded in 1932; the same year "telecommunication" was coined. Hargreaves and Southworth invented the circular waveguide. Karl Jansky accidentally discovered space radio noises. R. Darbord invented the UHF Parabolic Antenna. Armstrong tested FM in 1933, and F.M. radio was proposed. Cleeton and Williams created a 30 GHz C.W. oscillator using a split-anode magnetron. 1934: The FTC was founded. W.L. Everitt identified Class C amplifier working conditions. F. E. Terman showed a transmission line is resonant. German physicist Oskar Ernst Heil invented capacitive current regulation in FETs. He also patented electrical amplifier and control system innovations. Boonton Radio Corp.'s C.J. Frank created the Q-meter in 1935. Its "Quality Factor" was first suggested in 1926 as the coil's reactance-to-resistance ratio. The Eiffel Tower's peak has a T.V. transmitter. Watson-Watt patented the first aircraft-detection Radar in England. Hollmann patented the multi-cavity magnetron (granted in 1938). H. W. Doherty created the Doherty amplifier in 1936 at Bell Labs. Paul Eisler invented Printed Circuits. N. H. Jack invented the semi-rigid coaxial cable's thin, soft copper tube. Harold Wheeler used two flat copper strips side-by-side to build a low-loss, rollable transmission line. Friis and Beck designed the dual-polarization horn reflector antenna. The first radio telescope was erected in 1937 by Grote Rober. W. R. Blair invented the anti-aircraft Radar. Hansen, Varian, and Varian designed the reflex Klystron. Alex H. Reeves created pulse-code modulation for voice encoding. Chaffee found the perfect Class B load in 1938. IRE has antenna, receiver, and transmitter specifications. Shannon recognized parallels between electrical switching and Boolean algebra. Hewlett invented the Wien-bridge (R.C.) oscillator. P. H. Smith invented RCA's Smith Chart. RCA's N.E. Lindenblad created the coaxial horn antenna. John Turton Randall and Albert Boot invented the cavity magnetron for Radar. 1941: W. C. Godwin creates a direct-coupled push-pull amplifier with inverted feedback. Siemens and R. S. Ohl made Ge and Si junction diodes. Warner created the police two-way F.M. radio. 1943: H. J. Finden creates a frequency synthesizer. Rudolf Kompfner created the TWT. Chang invented R.C. frequency modulation. Edwards invented microwave mixers. Friis invented radio noise figures. Harold Goldberg proposed PFPM in 1944. E. C. Quackenbush designed VHF coaxial connectors for Amphenol. Paul Neil invented type N connections at Bell Labs. Maurice Deloraine, P. R. Adams, and D. H. Ranson filed patents for pulse displacement and time-slot exchange. The outcome was TDMA. Radio Research Lab invented 25-to-6-GHz radar jamming methods. 1946: S. L. Ackerman and G. Rappaport invent guided missile radio control. E.M. invented the spectrum analyzer. Mueller and Tyrrel invented the dielectric rod antenna in 1947. Kraus invented the helical antenna. W. Tyrell suggested hybrid microwave circuits, and H. E. Kallman invented the VSWR meter. W. H. Brattain, J. Bardeen, and W. Shockley invented the junction transistor in 1948. Ginzton and others paralleled pentodes to construct a distributed wideband amplifier. Shannon explained digital communications in "A Mathematical Theory of Communication." Paine described BALUN. E. J. Barlow described the Doppler Radar in 1949. Janssen invented the sampling oscilloscope in 1950. The MASER Principle was published in 1951. (Stimulated Microwave Emission). Paris' Laboratoire Central des Telecommunications created the first time-division multiplex system that linked subscriber lines with electronic gates that handled amplitude-modulated pulses. 1952: C. L. Hogan demonstrated a microwave circulator. 1955 - R. Isbell's periodic log antenna. John R. Pierce invented satellite communications. Sputnik, I sent telemetry signals for over five months in 1957. First transistor radio by Sony. Herbert Kroemer proposed the HBT in 1958. G. built the first I.C. in 1962. Robert-Pierre Marie invented the slot antenna. F. MOS IC and R. Hofstein. P. Heiman created W. Mortley, and S. Rowen invented SAW devices. IBM's John B. Gunn showed GaAs and InP diodes had microwave oscillations. IRE and AIEE merged to become IEEE (IEEE). Johnson, De Loach, and Cohen created the IMPATT diode oscillator in 1964. The launches of COMSAT and INTELSAT created a global network of communications satellites. 1969 saw Japan's first 2 GHz digital radio-relay system. ARPANET launched (precursor to the Internet). States began selling photolithographic quartz oscillators in 1971. AT&T Bell Labs started developing a cell phone in 1978. In 1980, GaAs MESFETs reached 10 W at 10 GHz in C.W. ATLAS I EM pulse simulator is the world's largest wooden structure (400 x 105 x 75 m). F. Laleari invented the broadband notch antenna in 1989. WWW began in 1990 [2].

1.3 WHY WE USE WIRELESS COMMUNICATION

The use of wireless technology has progressively increased the lives of the majority of people. In the office, at home, in stadiums, and even in vehicles, people rely on wireless technology for information, entertainment, communication, and other things. It is difficult to comprehend how so much was accomplished before wireless technology became a need in so many different industries and environments. Even though wireless is now practically a given in everything we do, its importance has not changed since its inception. Right now, wireless technology could be more important than ever. It does a lot, from information transfer and productivity improvement to speed, flexibility, and network efficiency. The dependence on Wi-Fi will only increase over time [3].

Accessibility: Wireless networks allow mobile users to access real-time information and roam throughout the company's facilities without losing network connectivity. This improves internal communication and productivity, which is not achievable with conventional networks. Because wireless networks do not require wires or cords, users may communicate even while traveling. Users are free to move around without losing connection. There is an increase in productivity as a result.

Easy installation: A wireless network may be set up more quickly and efficiently than a cable one. Additionally, it lessens the need for cumbersomely installed cables while increasing the risk to user safety because they can trip them up and fall. Users who wish to modify the network must update the wireless network to consider the new configurations. A wireless network system can replace wires, which are labor-intensive to install and dangerous to worker safety if tripped over. It may also be set up swiftly and compared to a conventional network.

Wider reach: The wireless network may be extended to regions of your business where wires and cables are unavailable. Wireless networks can extend further than conventional networks. They can be easily moved to places where wires and cables are hard to reach.

Flexibility: If the network changes in the future, updating the wireless network to support new configurations is straightforward. A wireless network setup makes it simple for the user to work from home. This network allows users to operate more productively and access client data.

Efficiency: Data transmission is upgraded and improved through wireless networks. Users may send information considerably more quickly through a wireless network.

Cost-effective: Although the initial cost of wireless networking may be slightly more significant, total costs over time are cheaper. It could also have a longer lifespan than a network connected conventionally. Wireless networks are economical because they are less expensive and simpler to set up. Although they make a significant initial investment, their overall costs decrease over time.

Increased Scalability: Wireless systems can be modified to meet the needs of certain applications. They can be easily changed and scaled to fit the needs of your business [4].

1.4 MULTIPLE ACCESS TECHNIQUES

Multiple accesses are a signal transmission scenario when two or more users want to interact with each other simultaneously via the same propagation channel. This situation occurs in a wireless communication system during uplink transmission.' On the uplink or reverse channel, several users may seek to communicate data at the same time. Collisions will occur if two or more users broadcast at the same time and there is insufficient coordination among the broadcasting users. Access mechanisms that result in collisions are random access and variants [5]. Access methods are multiplexing techniques that offer communications services to several customers across wired or wireless media with a single bandwidth. Communication channels cost money, whether cable connections or wireless spectrum segments. To generate a profit, suppliers of communications services must compel numerous paying customers to compete for few resources. Thanks to access techniques, numerous users can share these constrained channels, creating the economies of scale required for a successful communications firm. There are five direct access or multiplexing methods: Frequency division multiple access (FDMA), 'Time division multiple access (TDMA), Code division multiple access (CDMA), Orthogonal frequency division multiple access (OFDMA) and Spatial division multiple access (SDMA).

1.4.1 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

FDMA is the technique of separating a single channel or bandwidth into numerous distinct bands, each for use by a single user (Fig. 1). The signal spectra of the broadcasts to be conveyed can be accommodated by the width of each specific band or channel. Each subcarrier is modulated with the data to be delivered before they are all linearly blended.

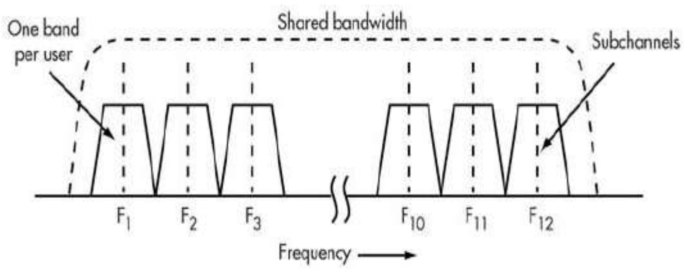


Figure 1.1: FDMA distributes the common medium bandwidth into independent channels. Each sub-channel is occupied by subcarriers that have been modulated by the data to be conveyed [6].

The cable television network is the most acceptable illustration of this. A single coax cable is the transmission medium for hundreds of TV channels and audio content delivered to households. The usable bandwidth of the coax cable ranges from 4 MHz to 1 GHz. The channels at this bandwidth are 6 MHz wide. A single TV station or channel initially utilized a single 6-MHz band. However, because of compression and multiplexing methods in each channel, modern digital technology allows numerous TV stations to share a single band [6].

Important Point: The difference in frequency between the forward and reverse channels is the same for all channels in the whole system.

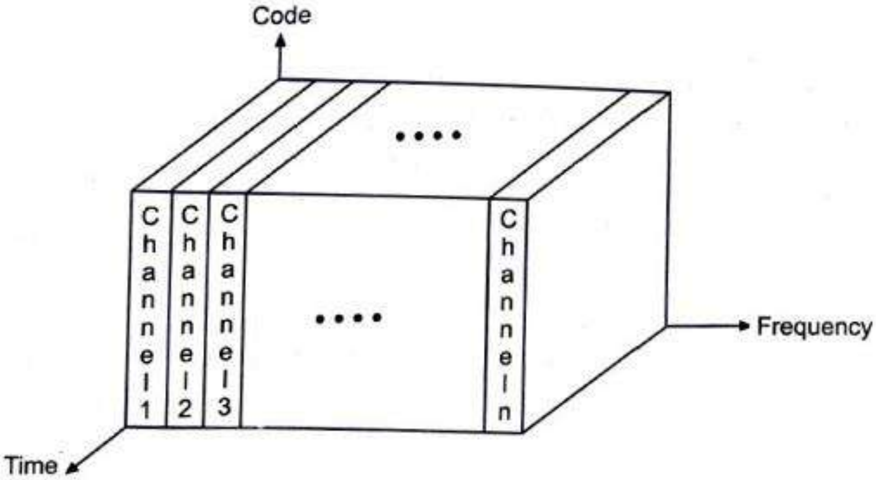


Figure 1.2: The figure above shows how the FDMA multiplexing scheme works, where the whole bandwidth is split into frequency slices and given to each user [5].

Salient Features of FDMA Scheme [5]

I. For FDMA to prevent interference from neighboring channels, adequate filtering is needed on the receiver side.
II. If a channel is not in use in the FDMA system, it will be idle and some other users will not utilize it. There is therefore a possibility of resource waste.
III. One phone circuit can be handled by an FDMA channel at a time.
IV. Less complexity exists.
V. Limited bandwidth.
VI. In FDMA, when the voice channel is given, both the mobile unit and the base station start sending at the same time.

1.4.2 TIME DIVISION MULTIPLE ACCESS (TDMA)

Time Division Multiple Access (TDMA), a complicated technique that necessitates exact synchronization between the transmitter and receiver. TDMA is used in digital mobile radio systems. Each mobile station cyclically assigns a frequency for a specific period's exclusive usage. A station is usually not given full access to the system's bandwidth for a specific period. The system's frequency is split into sub-bands, and TDMA is employed for multiple accesses in each. Carrier frequencies are the term for sub-bands. The term "multi-carrier systems" refers to the mobile system that uses this approach. TDMA is the foundation of the GSM (Global System of Mobile Communications) cellular phone system. Voice signals or data, such as messages or emails, can be sent within eight-time intervals. The radio spectrum is split into 200-kHz bands, and eight-voice calls are combined into one-channel using time division algorithms [5].

Three individuals utilized the frequency band in the case below. Specific time slots for sending and receiving data are allotted to each user. User "A" transmits first in this example, followed by User "B" and User "C." As a result, the peak power issue is exacerbated by burst communication.

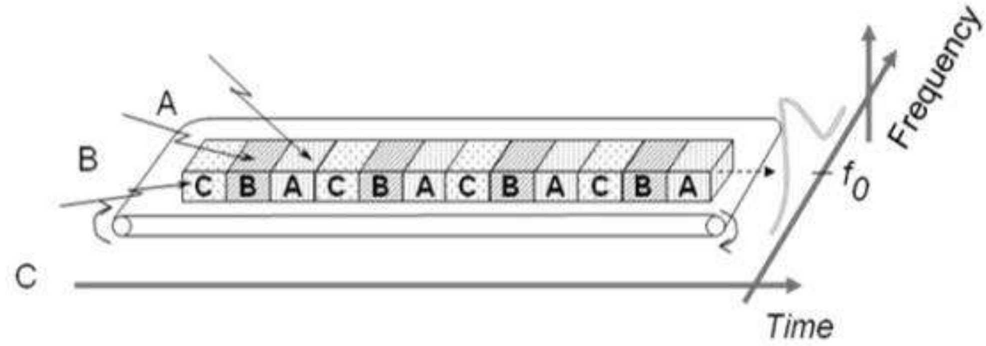


Figure 1.3: Time division multiple access.

Salient Features of TDMA [5]

I. In a TDMA multiple access scheme, each user uses the same carrier frequency, but their time slots do not overlap.

II. For the wideband system, there is no need for a guard band.

III. For the wideband system, there is no need for a narrowband filter.

1.4.3 CODE DIVISION MULTIPLE ACCESS (CDMA)

Another entirely digital method is CDMA. Because the digitized analog signal is dispersed over a broader bandwidth at a lower power level, it is sometimes referred to as a spread spectrum. Direct sequence spread spectrum (DSSS) is another name for this technique (Figure 1.8). The signal is diffused by processing the serial data form of the digitized and compressed speech signal in an XOR circuit alongside a much higher frequency-chipping signal. In the CDMA IS-95 standard, a 1.2288-Mbit/s chipping signal sends the digitized and compressed voice at a rate of 13 kbits/s.

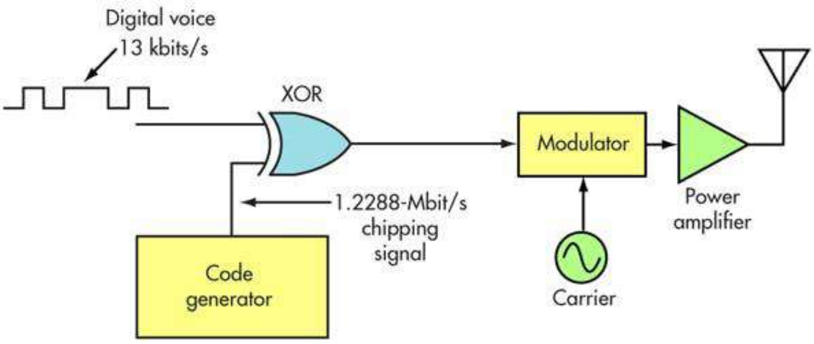


Figure 1.4: CDMA uses a spread-spectrum technique. In an XOR logic circuit, the compressed and digitalized speech signal is processed alongside a higher-frequency coded chipping signal. As a result, the digital voice may be shared with other users using various codes and is dispersed across a considerably greater bandwidth [6].

A pseudorandom code generator that gives each channel using a unique code creates the chipping signal. The speech signal is dispersed using this coding across a 1.25 MHz bandwidth. The resultant signal is weak and more closely resembles noise. These signals can all be present on the same channel at once. For instance, utilizing 64 different chipping codes enables up to 64 users to simultaneously use a 1.25 MHz channel. A correlating circuit at the receiver locates, recognizes, and recovers a particular caller's code.

Since several users share the same channel, a near-far effect issue might arise. The primary benefit of CDMA over other multiple access protocols is a lower degree of interference. The receiver selectivity tunes to receive the intended signal of the user since each user or subscriber is given a unique pseudo-random code word that is orthogonal to all other code words of remaining users at the receiving end. To prevent issues with near-far communication, CDMA uses proper power management methods.

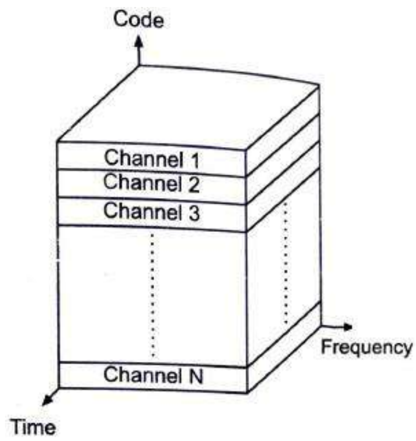


Figure 1.5: Code Division Multiple Access [5].

Salient features of CDMA multiple access schemes

I. CDMA may be susceptible to a self-jamming issue if the spreading sequences are not perfectly orthogonal from one user to another. Therefore, it is necessary to properly arrange and incorporate this spreading sequence or pseudo-random noise code into the message signal.
II. In CDMA, a radio signal strength indicator (RSSI) is utilized for improved power management.
III. Comparing CDMA to TDMA and FDMA, the former has a superior soft capacity limit.
IV. Given that separate codes are assigned for each purpose, CDMA experiences less interference issues. More than other multiple access strategies, this one is used in defense-related fields.

1.4.4 ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA)

OFDMA is the name of the access technique used in Long-Term Evolution (LTE) cellular systems to handle multiple users within a given bandwidth. A channel is divided into numerous small, orthogonal bands using a modulation technique called orthogonal frequency division multiplexing (OFDM), which keeps the bands apart to avoid interference. Each band is divided into hundreds or perhaps thousands of 15 kHz wide subcarriers. The necessary data is modulated onto the subcarriers after being divided into many slower bit streams. Within each sub-channel data stream, the data that will be broadcast is bundled using time slots (Figure 1.10). As a result of its excellent spectrum efficiency, this approach provides exceptionally high data rates. Furthermore, the consequences of multipath propagation are less significant.

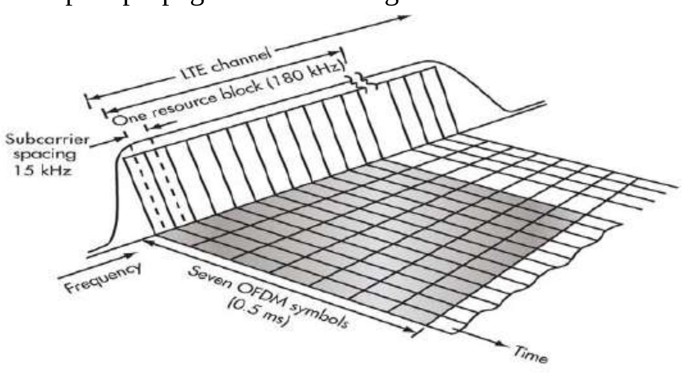


Figure 1.6: OFDMA gives each user a group of subcarriers. The subcarriers are among the several subcarriers utilized in the LTE implementation of OFDM. Time-stretched versions of voice, video, or other forms of data are delivered across some of the subcarriers.

1.4.5 SPATIAL DIVISION MULTIPLE ACCESS (SDMA)

The SDMA physical separation techniques make it possible to share wireless channels. A single channel, for instance, may be used concurrently if users are enough apart to avoid interference. In cellular radio networks, the method, also known as "frequency reuse," is employed. To lessen interference, cell site spacing has been increased.

In addition to space, directional antennas are used to reduce interference. To facilitate frequency sharing, the majority of cell sites provide 120° sectors with three antennas (Figure 1.11a). Dynamic beam shaping is a technique used by modern technologies like smart antennas and adaptive arrays to focus information into narrow beams that only reach specific users while rejecting everyone else (Figure 1.11b).

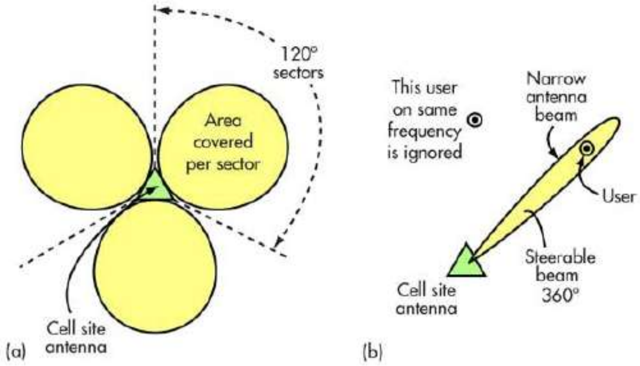


Figure 1.7: By separating users using directional antennas, SDMA divides users using common frequencies. To divide their coverage into distinct 120° sectors, most cell sites feature three antenna arrays (a). Beam formation is used by adaptive arrays to target certain users while disregarding any others using the same frequency (b) [6].

Polarization division multiple accesses (PDMA), a distinctive SDMA variant, divides signal using various antenna polarizations. Then, two distinct signals can operate on the same frequency, one broadcasting a signal with vertical polarization and the other with horizontal polarization. By separating users using directional antennas, SDMA divides users using common frequencies. To divide their coverage into distinct 120° sectors, most cell sites feature three antenna arrays (a). Beam formation is used by adaptive arrays to target certain users while disregarding any others using the same frequency (b) [6].

1.5 WIRELESS NETWORK STANDARDS

There are many distinct wireless data technologies, some of which are directly competitive with one another and others created for particular uses. Many measures may be used to assess wireless technology, some of which are detailed on this page. Following is a list of standards in order of increasing range:

1.5.1 WPAN AND WSAN

Personal Area Network (PAN) systems are created for close-proximity communication between gadgets that a single person normally controls. Examples include heart rate monitors that can communicate with watches and wireless mobile phone headsets. These technologies include ANT, UWB, Bluetooth, ZigBee, and Wireless USB standards.

Wireless Sensor Networks (WSNs) are collections of low-cost, low-power gadgets that wirelessly connect in order to gather, exchange, and sporadically act upon data gathered from their actual surroundings. A WSAN could be made up of sensors placed all over an agricultural site to measure the amount of water in the soil, send the information to a computer in the main office for trend modeling and analysis, and maybe even turn on automatic watering spigots if the level is too low [7]. Usually, nodes are connected in a mesh or star topology. While the majority of individual nodes in a WSAN are anticipated to have a constrained range (Bluetooth, ZigBee, 6LoWPAN, etc.), specific nodes may be able to communicate over greater distances (Wi-Fi, cellular networks, etc.), and anyone WSAN can cover a large area of the globe.

Some WPAN and WSAN standards are given below:

6LoWPAN: An abbreviation for IPv6 over Low-Power Wireless Personal Area Networks is 6LoWPAN [8]. The IETF's Internet working group's 6LoWPAN working group is no longer active [9]. The notion of 6LoWPAN was inspired by the notion that "the Internet Protocol could and should be applied even to the tiniest devices"[10] and that low-power, low-processing-power devices ought to be allowed to take part in the Internet of Things [8]. The 6LoWPAN group developed encapsulation, header compression, neighbor finding, and other technologies to support IPv6 on IEEE 802.15.4-based networks. Although the physical and MAC levels that IPv4 and IPv6 protocols operate on are often unimportant, IEEE 802.15.4's low power requirements and short packet size make it advantageous to adapt to these layers [11].

Bluetooth: Bluetooth is a wireless technology standard for delivering data over short distances between fixed and mobile devices using UHF radio waves in the ISM bands 2.402 GHz to 2.48 GHz, as well as for establishing personal area networks (PANs) [12]. It is mostly used to replace cable connections, send data between nearby portable devices, and couple wireless headphones with cell phones and music players. The most common mode has a 2.5 milliwatt maximum transmission power and a rather short range of up to 10 meters (33 feet) [13].

IEEE 802.15.4: Technically speaking, IEEE 802.15.4 specifies how a low-rate wireless personal area network operates (LR-WPAN). The standard was developed in 2003 by the IEEE 802.15 Working Group, which is also in charge of maintaining it. For LR-WPANs, it specifies the physical layer and media access control. The specifications for ZigBee, ISA100.11a, Wireless HART, MiWi, 6LoWPAN, Thread, and SNAP all enhance the standard by specifying the top layers that are not covered by IEEE 802.15.4 and act as their own standards' bases. The IPv6 version of the Internet Protocol (IP), which is used by higher levels like Thread, is specifically bound across WPANs by 6LoWPAN [14]."

Thread (network protocol): Thread is a mesh networking system for the Internet of Things (IoT) that is IPv6-based and low power [15]. Thread is dependable and secure to improve intelligent home and building experiences, and offers quick reaction times, extensive coverage, and years of battery life. The End-User License Agreement (EULA) states that "Membership in Thread Group is essential to implement, practice, and ship Thread technology and Thread Group standards," must be accepted to use the Thread protocol specification, which is provided without charge [16].

Ultra-wideband: Ultra-wideband (UWB, ultra-wideband, ultra-wideband, and ultra-band) is a radio technology that can make use of a sizable portion of the radio spectrum while using very little energy for short-range, high-bandwidth communications. Uncooperative radar imaging is one of the typical applications of UWB. The most recent applications focus on tracking, tracking applications, and collecting sensor data [17] [18]. High-end smartphones with UWB capability started to debut around 2019.

Wireless USB: The Wireless USB Promoter Group developed Wireless USB (Universal Serial Bus), a short-range, high-bandwidth wireless radio communication protocol to enhance the accessibility of all USB-based technologies. It was distinct from the Cypress Wireless USB solutions and had nothing to do with Wi-Fi. The WiMedia Alliance, which stopped operating in 2009, preserved it. Even though the USB Implementers Forum doesn't like this and prefers to call the technology "Certified Wireless USB" to make it stand out from the competing UWB standard, "WUSB" is a common way to shorten "Wireless USB" [19].

ZigBee: In order to create personal area networks utilizing small, low-power digital radios, such as those used for home automation, gathering data from medical equipment, and other low-power, low-bandwidth needs, ZigBee is an IEEE 802.15.4-based standard for high-level communication protocols. Small-scale applications that require wireless communication are the target market for ZigBee. ZigBee is therefore a proximity (i.e., personal area) (low power, low data rate) wireless ad hoc network [20].

ANT (network): ANT is a multicast wireless sensor network technology developed and commercialized by ANT Wireless that is proprietary (but open access) (a division of Garmin Canada).In particular, it offers personal area networks (PANs) for activity trackers. Before being acquired by Garmin in 2006, Dynastream Innovations launched ANT in 2003 and the low-power ANT+ standard in 2004 [21].

1.5.2 WLAN

A wireless local area network (WLAN) is utilized for communications across greater distances. WLANs are frequently referred to by their brand name in commerce, Wi-Fi. These devices offer wireless connectivity to other systems on the local network, including PCs, shared printers, similar devices, or even the internet. A WLAN often provides substantially faster internal network rates and latency than the typical consumer's Internet connection. DECT and HIPERLAN are two older technologies that support WLAN. However, they are no longer widely used. WLANs cannot typically migrate seamlessly from one network to another since they are reasonably localized [7].

WIFI: A collection of wireless network protocols built on the IEEE 802.11 standards make up Wi-Fi, often known as Wi-Fi. These protocols let nearby digital devices to communicate through radio waves, which is widely used for local area networking and Internet access. These are the computer networks that are utilized the most throughout the globe. At home, they have worldwide employment. Small office networks to connect desktop, laptop, tablet, smartphone, smart TV, printer, and intelligent speaker devices to one another and to a wireless router to connect them to the Internet, as well as wireless access points in public places like coffee shops, hotels, libraries, and airports to provide the general public with mobile device Internet access [22].

1.5.3 WWAN

Cellular networks, also known as wireless wide-area networks (WWANs), are built for smooth movement from one access point (commonly referred to as a base station) to another, enabling seamless coverage for vast regions. The 2nd generation (2G), 3G, and 4G cellular network technologies are frequently distinguished. Initially, 2G networks were digital cellular systems that were voice-centric or even voice-only (as opposed to analog 1G network). Typical 2G technologies include GSM and IS-95 with extensions through GPRS, EDGE, and 1xRTT, giving users of the networks' initial voice-centric 2G services access to the Internet. According to the ITU, EDGE and 1xRTT are both 3G protocols. However, they are sometimes promoted as 2.9G due to their disproportionally slow speeds and significant delays compared to accurate 3G technology. The combined circuit and packet switched data and voice services offered by accurate 3G systems, such as EV-DO and W-CDMA (including HSPA and HSPA+), often start at far higher data rates than 2G networks with their extensions. These services may all be utilized to offer remote regions integrated mobile voice and Internet connectivity. Even greater bitrates and several architectural advancements offered by 4G networks are available; however, they may not always be noticeable to the end user. WiMAX and LTE are the two 4G technologies now widely used. The two networks are entirely packet-based and do not support conventional voice circuits. These networks offer VoIP or VoLTE voice services [7].

EDGE: The phrase "Enhanced Data rates for GSM Evolution" (EDGE), also spelled "Enhanced GPRS" (EGPRS), "IMT Single Carrier" (IMT-SC), or "Enhanced Data rates for Global Evolution," refers to a GSM improvement that allows for greater data transfer rates while being backward-compatible. The ITU lists EDGE as a pre-3G radio technology and defines 3G. The first company to introduce EDGE on GSM networks was Cingular (now AT&T) in the United States in 2003 [23].

EVDO: A telecommunications standard called Evolution-Data Optimized (EV-DO, EVDO, etc.) allows for the wireless transport of data using radio waves, generally for broadband Internet access. The EV-DO standard, which enables high data speeds and may be implemented alongside voice services offered by a wireless carrier, is an extension of the CDMA2000 (IS-2000) standard. It employs cutting-edge multiplexing strategies to increase throughput, including time-division multiplexing (TDM) and code-division multiple access (CDMA). It is a member of the CDMA2000 family of standards and has been embraced by many mobile phone service providers worldwide, especially those who previously used CDMA networks. Additionally, the Globalstar satellite phone network uses it [24].

GPRS: General Packet Radio Service (GPRS) is a packet-oriented mobile data standard that runs on the 2G and 3G cellular communication networks' global infrastructure for mobile communications (GSM). GPRS was created by the European Telecommunications Standards Institute (ETSI) as a replacement for the CDPD and i-mode older packet-switched cellular technologies. It is looked after by the Third Generation Partnership Project (3GPP) [25].

HSPA: High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access, two 3G mobile telecommunications protocols based on WCDMA, are combined to form High-Speed Packet Access (HSPA) (HSUPA). It improves and expands the functionality of these networks. The Evolved High-Speed Packet Access (HSPA+) 3GPP standard was introduced in late 2008, and broad adoption began in 2010. The current standard allows data rates for the downlink and uplink of up to 337 MBit/s and 34 MBit/s, respectively. These speeds are seldom reached in reality [26].

LTE: Long Term Evolution (LTE), also known as the E-UTRAN (Evolved Universal Terrestrial Access Network), was first presented in 3GPP R8 (EPS). Release 8 was the foundation for the initial generation of LTE devices and was frozen in December 2008. The LTE specs have the extra benefit of improvements being included in all successive 3GPP releases, making them relatively reliable [27]. The project name for creating a high-performance air interface for cellular mobile communication systems is LTE. It is the final phase of the transition to the fourth generation (4G) of radio technology intended to boost the speed and capacity of mobile phone networks. While previous generations of mobile telecommunication networks were referred to as 2G or 3G, LTE is promoted as 4G [28].

UMTS: The third generation radio technology created inside 3GPP is called UMTS. The radio access standards provide for Time Division Duplex (TDD) and Frequency Division Duplex (FDD) variations. These enable the potential re-use of bands now devoted to 2G services and are described in 3GPP Technical Specifications 25.101 (FDD) and 25.102 (TDD) [29]. The TDD option also allows for many chip rates, enabling UTRA technology to work in various bands and coexist with other radio access technologies. Although the ITU has since given additional bandwidth on a regional basis, UMTS still contains the primary W-CDMA method employing paired or unpaired 5 MHz wide channels in the internationally agreed spectrum around 2 GHz.

WiMAX: WiMAX is one of the most widely used broadband wireless technologies. WiMAX systems are expected to provide commercial and residential customers with reasonably priced broadband access services. In order to provide broadband connectivity to client premises, WiMAX, a standardized wireless version of Ethernet, is primarily intended to replace wire technologies (such as Cable Modems, DSL, and T1/E1 lines). More specifically, WiMAX is a trade organization for the industry that was founded by leading suppliers of communications, components, and equipment to promote and certify the compatibility and interoperability of broadband wireless access equipment that complies with the IEEE 802.16 and ETSI HIPERMAN standards. WiMAX would operate at quicker speeds over greater distances and with more users, similar to Wi-Fi. WiMAX can go past the physical limitations of traditional wired infrastructure and provide service even in places that are difficult for wired infrastructure to reach. WiMAX was founded in April 2001 to aid in the publication of the initial 10-66 GHz IEEE 802.16 specifications. WiMAX uses 802.16 whereas the Wi-Fi Alliance uses 802.11 [30].

IMTS: AT&T developed the improved mobile telephone service in 1964 (IMTS). This system enabled automated dialing, entire duplex operation, and channel finding. There were 11 channels accessible at first, but in 1969, 12 more channels were added. The IMTS system faced high demand for a relatively scarce channel resource because there were only 11 channels accessible for all system users in a specific geographic area (such as the metropolitan area around a big city). Each base-station antenna needed to be mounted on a tall building and broadcast with great power to reach the full-service region. Due to the system's high power requirements, all subscriber units in the IMTS system were motor vehicle-based devices with sizable storage batteries [31].

AMPS: Advanced Mobile Phone Service (AMPS) is a cellular telephone service standard in the United States that is also utilized in other countries. It is based on the Federal Communications Commission's (FCC) 1970 allotment of the first electromagnetic radiation spectrum for cellular service. AMPS, which AT&T introduced in 1983, quickly rose to become one of the country's most frequently used cellular systems. AMPS gives cellular phone users frequency bands inside the 800 and 900 Megahertz (MHz) spectrum. Each service provider can use half of the 824-849 MHz band for cellular phone signal reception and half of the 869-894 MHz range for cellular phone transmission. The bands are broken up into 30 kHz-wide subbands known as channels. Reverse channels are used for receiving, whereas forward channels are used for sending. Frequency Division Multiple Access divides the spectrum into sub-band channels (FDMA) [32].

NMT: NMT, or Nordic Mobile Telephone, is the name of the analog mobile telephone network that the Nordic nations developed together. After ten years of development, the public was given access to NMT, a completely automated network. Despite being a Nordic idea, the NMT system did not originate in the Nordic nations. The concept was initially introduced in Saudi Arabia in 1981. A few months later, Sweden and Norway also started using the technique. The following year, Finland and Denmark began, and a few years later, Iceland joined. The Nordic region's network had 110,000 customers by 1985, making it the largest mobile network at the time [33].

TACS: Total Access Communication System (TACS) is a mobile communications system utilized in the United Kingdom and a few other countries. The Advanced Mobile Phone System (AMPS), created by AT&T for the United States of America, is the source of TACS. In the UK, TACS was first made available in 1985. It was introduced with great success. TACS was employed in over 25 different nations. TACS is an analog FM system that uses the 890-915 MHz/935-960 MHz spectrum, which eventually saw the introduction of GSM. The main variations are radio frequencies, radio channel bandwidth, and data signaling speeds. With 1000 duplex channels available in the 900 MHz spectrum, the radio channel bandwidth was 25 kHz. The data signaling rate had to be lowered since TACS employed a narrower radio channel bandwidth than AMPS, which had a bandwidth of 30 kHz. In Japan, TACS has been used in a modified form. JTACS was the name of the Japanese version. The primary distinction is its additional radio frequency band [34].

GSM: The Global System for Mobile Communications (GSM) standard was created by the European Telecommunications Standards Institute (ETSI) to define the protocols for second-generation (2G) digital cellular networks used by mobile devices such phones and tablets. It was first applied in Finland in December 1991. It was the industry standard for mobile communications by the middle of the 2010s, with over 90% of the market share and being used in more than 193 countries and territories [35].

1.6 DEVELOPMENT OF WIRELESS NETWORK

Mobile technology has advanced considerably since the launch of Motorola's first commercial mobile phone in 1983. We have significantly enhanced wireless connections and increased the functionality of our wireless communication system. Changes in mobile telephony have been noted as a new generation of mobile communication, regardless of the technology, protocols, services offered, or speed. Each of us has experienced different generations [36]. Here, we'll talk about the fundamental characteristics of these generations that set them apart from earlier ones [37].

Simply put, the "G" stands for "generation." "Each Generation" refers to a group of phone network standards that outline the technology implementation of several mobile phone systems. The technology needed to achieve a certain speed also rises. As an example, 1G gives 2.4 kbps; 2G provides 64 kbps and is based on GSM; 3G provides 144 kbps–2 Mbps; and 4G provides 100 Mbps–1 GBPS and is based on LTE technology [38].

Manufacturers of mobile phones and service providers typically divide wireless communication systems into various generations. First-generation (1G) systems are analog cordless and cellular telephones that are voice-oriented. Second-generation (2G) wireless networks include data- and voice-oriented wireless WANs and digital cellular and PCS systems. The third-generation (3G) networks combine packet-switched data services with cellular and PCS voice services to create a single network. Broadband local and ad hoc networks garnered much interest in addition to the unified 3G standardization operations, and they created their standards. One of the leading contemporary contrasts between these two waves is using licensed bands by 3G systems instead of unlicensed bands by broadband and ad-hoc networks [39].

1.6.1 ZERO GENERATION (0G -0.5G)

The term "0G" refers to mobile phone technology used before cellular phones became common. Although other briefcase variants were available, these mobile phones were often installed in vehicles like automobiles or trucks. If you can recall, so far in the past, wireless telephones began with what you may now refer to as 0G. There were just a few channels accessible in those pre-cell days, and you needed a mobile operator to arrange calls. Modern cellular mobile telephony technology was developed before mobile radIoTelephone networks. These systems are frequently referred to as 0G (zero generation) systems since they were the forerunners of the first generation of cellular cell phones. Push-to-talk (PTT), MTS (Mobile Telephone System), IMTS (Improved Mobile Telephone Service), AMTS (Advanced Mobile Telephone System), OLT (Norwegian for Offentlig Landmobil Telefoni, Public Land Mobile Telephony), and MTD were among the technologies utilized in 0G systems (Swedish abbreviation for Mobilelefonisystem D, or Mobile telephony system D) [40].

0.5G refers to a collection of technologies with more advanced features than the foundational 0G technologies. These early mobile telephone systems could be distinguished from earlier closed radIoTelephone systems by the fact that they were offered as a paid service on the public switched telephone network, with their phone numbers, as opposed to being a part of a closed network like a police radio or a taxi dispatch system. Although other briefcase variants were available, these mobile phones were often installed in vehicles like automobiles or trucks. The "head" (dial, display, and handset) of the transceiver (transmitter-receiver) were often located near the driver's seat and connected to the trunk of the car. They were offered for sale at several places, including two-way radio retailers. For simple voice communication, the prominent users were loggers, construction foremen, realtors, and celebrities [40].

Figure 1.8: Zero generation communication device.

1.6.1 FIRST GENERATION (1G)

This was the first iteration of mobile phone technology. Late in the 1970s, the first wave of commercial cellular networks went live. It took the 1980s for standards to be fully created. In 1987, Telecom established Australia's first cellular mobile phone network using 1G analog technology (now known as Telstra). Analog technology is 1G. These are the analog telecommunications standards that were put into place in the 1980s and utilized until 2G digital telecommunications replaced them. The highest speed of 1G is 2.4 Kbps [38]. As a result, the phones frequently had missed conversations, had poor voice security, and had limited battery life. Because they utilized several cell sites and had the ability to transfer calls from one cell site to the next as the user moved from one cell to the next during a conversation, first-generation mobile phones were distinct from those of the previous generation.

Figure 1.9: 1G Mobile phone [43].

1.6.1.1 SALIENT FEATURE AND KEY BENEFITS OF 1G

I. The analog switching technique is employed.
II. Frequency modulation, or FM, is employed.
III. It utilizes the PSTN Core Network.
IV. Frequency: between 800 and 900 MHz.
V. The bandwidth is around 10 MHz.
VI. Access must be granted via FDMA methods.
VII. Only voice service is available.
VIII. Only capable of making basic phone calls [41].

1.6.1.2 DOWNSIDE OF 1G

I. Interferences were common with analog transmissions. Thus, communication was obtrusive.

II. Appropriate encryption techniques could not be supported by analog systems. Security was therefore a serious concern, and tapping was uncontrollable.
III. Experience interference issues.
IV. Limited capacity
V. Untrustworthy hand-off
VI. It provides subpar voice connections
VII. Because the voice communications were repeated in the radio towers, there is no security. [42] [43].

1.6.2 SECOND GENERATION (2G)

The analog technology of 1G was replaced with a digital system in the second-generation (2G) mobile phones. In Finland, it was introduced commercially as the GSM standard in 1991. Similar to 1G phone, 2G phones lacked any global standards. PCS, another name for 2G systems, stood for personal communications services (PCM) [44]. The International Telecommunication Union (ITU) is in charge of maintaining and describing a set of mobile communication standards called second-generation wireless. Compression and multiplexing of speech data are accomplished using CODEC (compression-decompression) techniques. This innovation allows for the bundling of more calls per unit of bandwidth and the provision of services like SMS and email for 2G users. Error checking is present, and speech quality may be enhanced by decreasing the noise floor. Two different technologies make up 2G. Time division multiple access (TDMA) protocols include GSM, which is widely used over the globe, the Japan-only PDC, iDen, which is utilized in select regions of the US and Canada, and D-AMPs, which was GSM's forerunner [45].

Figure 1.10: 2G Mobile phone [46].

1.6.2.1 SALIENT FEATURE AND KEY BENEFITS OF 2G

I. Reduced static and a clear voice
II. The network can accommodate more users at once.
III. Better utilization of the spectrum.
IV. Cheaper and more compact phones.
V. Roaming is encouraged.
VI. Speech and data transmissions are encrypted digitally.
VII. Minimal use of energy (mobile phones are becoming more energy efficient).
VIII. It enables the digitization and compression of voice transmissions. They are therefore more effective than 1G on the frequency spectrum.
IX. They offered SMS text messaging as a kind of mobile data services.
X. Signals for both data and audio are digitally encrypted. As a result, fraud and eavesdropping security significantly improved.
XI. Less battery power is used by digital transmissions. Mobile sets are therefore far more energy-efficient than their 1G equivalent [47].

1.6.2.2 DOWNSIDE OF 2G

I. The location and closeness of towers play a significant role.
II. Due to its unpredictable, on-off nature, a digital signal abruptly fades or goes altogether.
III. There are more dropped calls and voices that seem false every day.
IV. incapable of handling intricate data, like movies.
V. We needed strong digital signals.
VI. If digital signals were weak, there was no network coverage there [48].

1.6.3 THIRD GENERATION (3G)

The 3rd Generation Partnership Project (3GPP) was established in 1998 to promote the creation of new networks as an improvement over the GSM (Global System for Mobile Communications) 2G technology already in use.IMT-2000, or "International Mobile Telecommunications," was a collection of technical standards released by 3GPP in 2000 that outlined the industry's goals for a third-generation system. Seven more years would pass until the first iPhone was released. However, the need for integrated mobile, phone, data, internet, and multimedia services via 3G was recognized. Another objective was maintaining connectivity; new systems would require users to travel to countries without changing phone numbers or devices. The standard states that 3G would offer far faster data transfer speeds, including a minimum of 2Mbit/s for stationary devices and 348 kbit/s for moving vehicles. The typical speed range for 2G networks was 9.6 kbit/s to 28.8 kbit/s [49].

Figure 1.11: 3G Mobile phone [53].

1.6.3.1 SALIENT FEATURES AND KEY BENEFITS OF 3G

I. 2.05 Mbits/second to stationary devices.
II. 384 Kbits/second for slow-moving devices, such as a phone carried by a person strolling.
III. For quick devices, such as mobile phones in moving automobiles, 128 Kbits/second is recommended.
IV. International Mobile Telecommunications Standard (IMT-2000) standards of the International Telecommunication Union are met by 3G networks (ITU).
V. In 1998, the first 3G services were accessible.
VI. With a data transfer rate of more than 0.2Mbps, it offers high-speed transmission.
VII. Both phone and data services for international roaming are offered.
VIII. It provides cutting-edge multimedia access, including the ability to watch videos, listen to music, and perform music.
IX. It enables you to access all the sophisticated features of the Internet, including audio and video pages.
X. It made wide-screen smartphones more widely used and improved viewing of mobile websites, movies, and mobile televisions possible. [50] [51].

1.6.3.2 DOWNSIDE OF 3G

I. Base stations must be located closer to one another (at a higher cost).

II. Astronomical expenses for spectrum licenses, network development, subscriber handset subsidies, etc.
III. Various phones are required.
IV. Inadequate bandwidth
V. Power use is excessive.
VI. Cost a lot of money and call for a nearby base station.
VII. Cost of a spectrum license.
VIII. High costs for 3G smartphones.
IX. 3G-capable mobile device.
X. Connection rate.
XI. Different 3G phones are required.
XII. In comparison to a 2G mobile phone, a 3G cell phone is more expensive.
XIII. Roaming, collaboration, and data/voice have not yet been deployed [52].

1.6.4 FOURTH GENERATION (4G)

The fourth generation of mobile technology, or 4G, is called coming after the 2G and 3G networks that came before it. However, slower than 5G, 4G network design delivers considerable speed gains over older 3G networks. Since LTE is just one form of 4G network, the term "4G LTE" is occasionally used. However, this is incorrect technically. Most mobile network service providers currently use this cutting-edge technology. Standard 4G can provide download rates of about 14 Mbps, which is over five times quicker than the 3G network. In reality, 4G networks have download rates of up to 150 Mbps, enabling users to download gigabytes of data in seconds instead of hours, as with 3G networks [54].

Figure 1.12: 4G Mobile Phone [55].

1.6.4.1 SALIENT FEATURE AND KEY BENEFITS OF 4G

I. Improved spectral effectiveness.
II. High rate.
III. large capacity
IV. A lot of bandwidth.
V. Severe network security.
VI. High usability may be utilized with any technology, anytime, anyplace.
VII. encouragement of low-cost multimedia services
VIII. Inexpensive per bit.
IX. It is an interconnected network of several protocols.
X. Method for inexpensive communication.
XI. greater accessibility to services and programs
XII. The usage of synchronization is increased.
XIII. There is provision for machine-to-machine communication.
XIV. It has quality, portability of services, and accessibility worldwide [56].

1.6.4.2 DOWNSIDE OF 4G

I. Battery use increases.
II. Implementation is challenging.
III. Require sophisticated hardware.
IV. It was necessary to use 4G technology.
V. A next-generation network requires expensive hardware, which is still the case.
VI. More difficulties with the network's security exist.
VII. 4G services are still not widely available.
VIII. There is no established standard for network protocol.
IX. High consumer value for data.
X. I require several phones.
XI. Power use is excessive.
XII. Data or voice cooperation, as well as roaming, have not yet been introduced.
XIII. Cost a lot of money and call for a nearby base station [56].

1.6.5 FIFTH GENERATION (5G)

The term "5G" refers to the fifth-generation mobile network. The latest wireless standard for mobile devices follows the 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network to connect practically everyone and everything, including machines, objects, and devices. More customers will have access to 5G wireless technology's multi-Gbps peak data rates, incredibly low latency, improved dependability, enormous network capacity, and a more consistent user experience. Performance and efficiency improvements allow new user experiences and connect new industries.

The basis of 5G is orthogonal frequency-division multiplexing, or OFDM. In order to reduce interference, it is a method for modulating a digital signal over some channels. 5G uses OFDM principles in addition to the 5G NR air interface. 5G also uses sub-6 GHz and mmWave, which have wider bandwidths. Similar to 4G LTE, 5G OFDM operates by utilizing mobile networking principles. On the other hand, by making ONFD far more adaptable and scalable, the new 5G NR air interface can enhance it. This may enable more devices and individuals to use 5G for various uses.

Greater bandwidth will be possible with 5G by extending the use of spectrum resources from the sub-3 GHz used in 4G to 100 GHz and beyond. MmWave (e.g., 24 GHz and higher) and lower bands (e.g., sub-6 GHz) are possible operating bands for 5G, which will deliver exceptionally high capacity, multi-Gbps speed, and low latency. In addition to offering faster and better mobile broadband services than 4G LTE, 5G is meant to create new service opportunities, such as connecting the massive IoT and enabling mission-critical communications. This is made feasible by a variety of novel 5G NR air interface design concepts, including a brand-new self-contained TDD subframe design [57].

Figure 1.13: 5G Mobile phone [58].

1.6.5.1 SALIENT FEATURE AND KEY BENEFITS OF 5G

I. It moves along at a rapid pace.
II. large capacity
III. More efficient.
IV. Increased battery life.
V. Extreme security.
VI. High rates of data.
VII. Inexpensive per bit.
VIII. More appealing and efficient.
IX. Voice, the Internet, and multimedia are all supported.
X. It has an excellent resolution.
XI. For mobile users, it offers a sizable bidirectional bandwidth.
XII. Affordability and accessibility.
XIII. Access to dynamic information.
XIV. Data bandwidth of at least 1 Gbps.
XV. It offers services of the highest caliber (QoS).
XVI. It is possible to offer nonstop, unbroken connectivity anywhere in the world.
XVII. All networks may be gathered on one platform thanks to this technology.
XVIII. Additionally, it provides service portability and worldwide access.
XIX. Both the uploading and downloading speeds are really fast.
XX. Simple to handle for the prior generation.
XXI. Using handsets, you may control your PCs [59].

1.6.5.2 DOWNSIDE OF 5G

I. Costly development infrastructure is required.
II. Many of the outdated (1G, 2G, 3G, and 4G) equipment would not be 5G-compatible, necessitating their replacement, which would be costly.
III. Problems with security and privacy still need to be resolved.
IV. A 5G phone is pricey.
V. Research on the feasibility of this technique is still in progress [59].

1.7 COMPARISON BETWEEN WIRELESS NETWORK GENERATION

Each successive generation of services is a substantial step (more like a leap) towards wireless communication's ultimate objective: to provide dependable, high-quality communication comparable to cable communication (optical fiber). The voyage of progress began with 1G in 1979 and is still going now, reaching 5G. To officially use the word G terminology, each generation's requirements must be completed. Each generation of mobile technology is standardized by organizations. Each generation includes specifications that must be satisfied to be included in that generation, including throughput, latency, and other factors. Every generation added to the studies and advancements made since the one before it. Up to the introduction of 2G, or the second generation, 1G was not used to describe wireless technology. When wireless networks transitioned from analog to digital, they represented a significant technological advance [38].

The signal strength, shown on any mobile device by acronyms like 2G, 3G, 4G, and 5G, determine the connection speed when it is online. A set of telephone network standards that outline the system's technology implementation is used to define each iteration of wireless broadband. Each generation of wireless communication provides a significant step closer to providing high-quality, dependable communication similar to wired communication. Due to the rapid advancement of mobile technology in recent years, mobile communication has increased in popularity. People can converse through mobile communication systems by sending messages and data to one another. With the most recent technology, these services are sent to the consumer in a concise amount of time. After the 1G and 2G eras lasted from the early 1900s through 2000, 3G first appeared in 2001. NTT DoCoMo in Japan developed the first 3G pre-commercial experimental network in the Tokyo area in May 2001. On October 1, 2001, NTT DoCoMo introduced the first 3G network for use in the marketplace.

The first 3G networks using the competing CDMA2000 1xEV-DO technology were introduced in 2002 by Monet in the United States, SK Telecom, and KTF in South Korea. Monet filed for bankruptcy afterward. By the end of 2002, Vodafone KK introduced the second WCDMA network in Japan (now Softbank). The Three/Hutchison group launched the first 3G networks in Europe using WCDMA in March in Italy and the United Kingdom. Additional eight 3G commercial launches occurred in 2003, including two EV-DO launches and six WCDMA launches. By the end of 2007, there were 295 million 3G network subscribers, or 9% of the global subscriber base. The market no longer carries phones from the second generation in Japan and South Korea.

There were questions about whether 3G would materialize and if it would be a commercial success earlier in the decade. By the end of 2007, it was evident that 3G was a reality and was on the way to becoming a successful business. However, 4G has only had a relatively short existence up to this point. Although it began in 2008, it has not yet been fully deployed. In September 2008, Sprint made history by being the first significant US carrier to roll out a 4G network in Baltimore. One-third of them use the EV-DO standard, and about two-thirds use the WCDMA standard. 3G telecom services generated over 120 billion dollars in revenue in 2007, and in several areas, 3G phones made up the bulk of newly activated phones. From 1G to 5G, all mobile communication generations are compared below. Table 1.1 shows the comparison of the generation of wireless communication.

Table 1.1: Comparison of wireless generations.

Technology	1G	2G	3G	4G	5G
Development	1970/1984	1980/1999	1990/2002	2000/2010	2010/2015
Requirements	No official Requirements Analog technology	No official Requirement s Digital Technology	ITU"s IMT-2000 required 144 kbps mobile, 384 kbps pedestrian, 2 Mbps indoors	peak data rates of up to 100 Mbit/s for high mobility and up to around 1 Gbit/s for low mobility	Up to 10Gbps data rate, 1-millisecond latency.1000times bandwidth per unit area. Up to 100 times the number of connected devices per unit area, 99.999% availability, and 100% coverage.
Data Bandwidth	1.9 kbps	14..4 kbps to 384 kbps	2 Mbps	2 Mbps to 1 Gbps	1Gbps & Higher (as demand)
Core network	`PSTN	PSTN Packet Network	Packet network	All IP Network	Flatter IP Network & 5G Network Interfacing (5G-NI)
Service	Analog voice	Digital Voice Higher capacity, packetized data	Integrated high-quality audio, video, and data	Dynamic information access, wearable devices, HD streaming; global roaming;	Dynamic information access, wearable devices, HD streaming; any demand of users; upcoming all technologies; global roaming smoothly;
Standards	NMT, AMPS, Hicap, CDPD, TACS, ETACS	GSM, GPRS, EDGE ETC.	WCDMA, CDMA 2000.	All-access convergence, including OFMDA, MC-CDMA Network-LMPS	CDMA & BDMA
Multiple access	FDMA	TDMA CDMA	CDMA	CDMA	CDMA & BDMA

Technology	1G	2G	3G	4G	5G
Switching	Circuit	Circuit Packet	Circuit Packet	Packet	All Packet
Frequency	800-900 Reference MHz	850-1900MHZ	1.6-2.5GHZ	2-8GHZ	3.3–4.2 GHz and 24–47 GHz
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

1.8 THE FIFTH GENERATION: RECORDS AND UPDATES

A once-in-a-generation innovation, 5G has the power to revolutionize our networked economy completely. Every day, new 5G news is reported from around the globe. Some organizations are launching 5G trials in new places, while others are stating when customers will be able to buy their new service. Yet, others are unveiling new ideas for how 5G will revolutionize the way we live. Right now, there aren't many places where a live, subscriber-based 5G network is operational; instead, most of them are in demo mode. However, many organizations are continually growing to build a full-fledged 5G network for customers to use. And Verizon can support the entire development of this new universe.

1.8.1 REQUIREMENTS

One of the significant challenges with 5G requirements is that several interested parties want the new 5G wireless technology to meet their specific demands. As a result, the list of needs is not entirely cohesive. No single technology will be able to satisfy all wants simultaneously. Due to these extremely diverse 5G requirements, many believe the new wireless system will act as a hub enabling various radio access networks to function together. At the same time, each serves a specific set of demands. There will probably be a need for various radio access networks since high-speed data download and ultra-low latency criteria cannot readily coexist with those for low data rates and extended battery life [59].

Availability: The proportion of users or communication lines within a particular geographic region for which the Quality of Experience (QoE) standards are met is referred to as availability.

Connection density: Connection density is calculated as the ratio of concurrently active users or devices in the region under consideration over a certain period to the area's size.

Cost: Infrastructure, user equipment, and spectrum licensing are the usual cost sources. A straightforward model might be built on the premise that an operator's total cost of ownership is proportionate to the number of infrastructure nodes, the number of end users' devices, and the spectrum.

Energy consumption: Energy per information bit and power per area unit are two common ways to describe energy consumption, with the former being more pertinent in urban settings and the latter in suburban and rural ones.

Experienced user throughput: Experienced user throughput is calculated by dividing the total data traffic (excluding control signals) that an end-user device generates on the MAC layer during a specific period.

Latency: The data traffic's MAC layer is a delay on the radio interface. One-Trip Time (OTT) and Round-Trip Time (RTT) latency definitions are pertinent. The time between when a data packet is delivered by the transmitting end and when it is received by the receiving end is known as the OTT latency. The amount of time between when a data packet is delivered by the transmitting end and when a receiving end acknowledgment is sent and received is known as the RTT latency.

Reliability: The broad definition of reliability is the likelihood that a specific amount of data has been successfully transported from a transmitting end to a receiving end before a specific deadline has passed.

Security: It's tough to gauge how secure a particular communication is while it's happening. Calculating how long a proficient hacker would take to get the data would be one method to put a number on it.

Traffic volume density: The total quantity of traffic exchanged by all devices in the region under consideration over a specific period divided by the area's size is known as the traffic volume density [60].

1.8.2 STANDARDS

Standards heavily regulate mobile telecommunications to achieve a scale of efficiencies. Technical standards are publications that offer specifications, particularly about technology, for mobile communications. Standard Development Organizations publish and uphold the standards (SDOs). These are subsequently employed to create goods (equipment) that support such technology.

IMT-2020: The International Telecommunication Union (ITU) Radio communication Sector (ITU-R) published the International Mobile Telecommunications-2020 (IMT-2020 Standard) standards in 2015 for 5G networks, devices, and services [61][62].

5G-NR: The 5G (fifth generation) mobile network uses the new radio access technology (RAT) known as 5G NR, which the 3GPP created. It served as the international benchmark for 5G networks' air interface. It is based on OFDM, same as 4G (LTE) [63].

1.8.3 FREQUENCY BANDS

The 5G spectrum refers to the radio frequencies used to carry data from user equipment (UE) to cellular base stations and on to the data's destination. Both 5G traffic and LTE networks will operate at sub-6 GHz frequencies. In areas with fewer people, the lower frequency bands will be used since, although moving more slowly, data can go farther on these frequencies.

Frequency range 1 (< 6 GHz): FR1, also known as sub-6, has a maximum channel bandwidth established of 100 MHz because to the constrained availability of continuous spectrum in this crowded frequency range. The band in this range that is most typically used for 5G is from 3.3 GHz to 4.2 GHz. Some people used the term "mid-band" frequency to describe the higher part of this frequency range, which was not used in earlier generations of mobile communication.

Frequency range 2 (24–54 GHz): In 3GPP Release 15, two-channel aggregation is supported, with the minimum and maximum channel bandwidths for FR2 defined as 50 MHz and 400 MHz, respectively. The capacity to accommodate rapid data transfer speeds increases with frequency. This frequency's signals have been labeled as mmWave. The frequency distribution is given below in Table 1.2.

Table 1.2: Frequency distribution for FR2 [64].

Band	*f* (GHz)	Common name	Uplink / Downlink (GHz)	Channel bandwidths (MHz)
n257	28	LMDS	26.50 – 29.50	50, 100, 200, 400
n258	26	K-band	24.25 – 27.50	50, 100, 200, 400
n259	41	V-band	39.50 – 43.50	50, 100, 200, 400
n260	39	Ka-band	37.00 – 40.00	50, 100, 200, 400
n261	28	Ka-band	27.50 – 28.35	50, 100, 200, 400
n262	47	V-band	47.20 – 48.20	50, 100, 200, 400
n263	60	V-band	57.00 – 71.00	100, 400, 800, 1600, 2000

1.8.4 TECHNOLOGY

We have introduced several technologies to establish the 5G network properly. Some of those are given below.

Massive MIMO: MIMO systems use multiple antennas at both the transmitter and receiver ends of a wireless communication system. Multiple antennas use space as a third dimension for multiplexing, in addition to time and frequency, to meet the system's bandwidth needs.

Edge computing: Edge computing is the usage of computing servers that are closer to the user. It improves data flow, reduces latency, and promotes service availability.

Small cell: Low-power cellular radio access nodes known as small cells have a range of 10 meters to a few kilometers. Both licensed and unlicensed spectrum are available to them. Small cells are crucial since 5G network radio waves can't travel over long distances due to their higher frequency.

Channel coding: In 4G, Turbo codes were used for channel coding. In 5G NR, polar codes are used for control channels and LDPCs (low-density parity check codes) are used for data channels.

1.8.5 APPLICATION

The future will undoubtedly be transformed by 5G. Numerous new uses that are currently impractical will be made possible, especially in metropolitan settings and cities. By 2050, the UN predicts that more than two-thirds of the world's population will reside in metropolitan areas or cities.

Increased agricultural output: To reduce expenses, resource consumption, and increase yields, smart farming is already being implemented thanks to enhanced computer capabilities and the Internet of Things (IoT). However, industry studies claim that by introducing a high-capacity connection to rural farming regions, 5G can increase the geographical reach of intelligent agriculture and cut expenses.

Improved distance learning: Restrictions from the pandemic era that forced remote learning highlighted the flaws in the present communication architecture. The networks on which students had to rely were unstable and inconsistent. More towns should have access to 5G's fast speeds, more capacity, and high dependability as telecom firms expand their 5G networks.

Intelligent logistics: IoT is increasingly used in logistics, especially transportation, to track cargo as they travel worldwide and across international boundaries.

The industry is also progressing with deploying autonomous cars on the road and warehouse operations.

Modern medical treatment: Another sector embracing 5G to grow and enhance operations is the healthcare sector. 5G can handle the crucial and life-or-death use cases expected in the medical industry. Analytics, patient monitoring, remote diagnostics, and robot-assisted surgery are just a few of the countless applications that healthcare businesses may employ for 5G. While permitting mobility within facilities in a way that wired networks cannot, the technology offers dependability and capacity that rival fixed-line networks.

Better production processes: 5G has a lot of potential for the manufacturing industry because it is more flexible than wired networks while still meeting the high capacity, high reliability, and low latency needs of the industry. The capacity to alter automated industrial processes so they can more swiftly adapt to changing market demands is supported by 5G.

Modernized oil, gas, and mining operations: The mining, oil, and gas sectors, which frequently operate in challenging and distant places, will benefit from modernization thanks to 5G. Due to financial and logistical challenges, many facilities cannot now deploy wired networks, and they are unable to rely on 4G/LTE networks to manage significant amounts of mission-critical data. Because 5G can enable the extensive industrial IoT (IIoT) buildout required to monitor working conditions and control automated machines, more businesses are already utilizing it. Additionally, 5G and edge computing might enable the oil and gas sector to benefit from the enormous quantity of data that equipment produces.

More customized and efficient retail: Retailers attempt to improve consumer engagement and offer personalized experiences by combining digital and in-person services. Many are looking to next-generation technology, including a 5G connection, to make it possible. For instance, sensors provide data to analytics systems to better manage inventory, so consumers don't find empty shelves, and customized marketing catered to each customer's particular demands. Augmented reality to assist customers in picturing furniture in their own houses.

Better government services and administration: Municipalities all around the world are putting a variety of technologies into place to establish "smart cities," which connect people, buildings, and other infrastructure to ensure that everything moves as securely and efficiently as possible. For instance, a city can collect and examine endpoint data on traffic flow and then utilize the findings to reroute motorists away from crowded locations. A system with many moving components needs 5G, driving significant investment in this area.

Improved and more reliable utilities: Smart grids depend on a massive IoT ecosystem with a wide distribution of endpoint sensors, edge devices, and analytics tools. That calls for the kind of connection that 5G offers.

Increasing labor force assistance: Workers across sectors might be significantly impacted by 5G. It can support remote work with a quicker and more dependable connection, giving enough resilience to enable even mission-critical remote work. Utilizing augmented reality and other cutting-edge technology similarly facilitates distant communication. And it backs instruction using AI and related tools [65].

1.8.6 CHALLENGES FOR 5G

Radio technology has advanced quickly throughout the course of history, as we can see. The journey spans from 1G to 5G and is almost 40 years old (considering 1G in the 1980s and 5G in the 2020s). Since challenges are a necessary component of every new development, 5G also faces considerable challenges. On the other side, the key challenges we have encountered along the road have been a lack of infrastructure, subpar research techniques, and cost.

Inter-cell Interference: One of the fundamental technical problems to resolve is this. Traditional macro cells and contemporaneous tiny cells have different sizes, which will cause interference.

Efficient Medium Access Control: User throughput will be limited, there will be a lot of latency, and hotspots will not be able to support cellular technology to deliver high throughput in a situation where there are a lot of access points and users need to deploy terminals.

Traffic Control: In contrast to the typical human-to-human traffic in cellular networks, a significant number of Machine-to-Machine (M2M) devices in a cell may present serious radio access network (RAN) challenges, resulting in overload and congestion.

Multiple Services: Unlike the radio signal services already available, 5G would have the significant issue of delivering services to a wide range of networks, technologies, and devices operating across several regions. To meet people's high expectations, standardization must bring about wireless services that are dynamic, universal, user-centered, and full of data.

Infrastructure: For academics, the adoption of 5G services and their standardization present technical challenges.

Sensing, Navigation, and Communication: The availability of the radio spectrum, which is used to send signals, is very important to these services. Even though 5G technology has powerful processing power and can analyze a huge amount of data from many different sources, it needs a bigger infrastructure to support it.

Security and Privacy: One of the biggest obstacles that 5G must overcome to safeguard user data is this. 5G will have to describe these unknowns in order to deal with the growing global security risks related to trust, privacy, and cybersecurity.

Laws governing the Internet: The rapid and widespread 5G technology may lead to a rise in cybercrime and other forms of fraud. As a result, cyber law regulation is a crucial subject primarily of a governmental and political (national and international) character [66].

Chapter-2
Internet of Things (IoT): A Massive Connection

2.1 INTRODUCTION

The term "Internet of Things" (IoT) refers to a hypothetical scenario in which countless numbers of objects connected by IP (Internet Protocol) networks would have intelligence, communication channels, and sensing and actuation capabilities built into them. Our current Internet underwent a fundamental transformation from being hardware-driven (computers, fibers, and Ethernet connections) to market-driven as a result of connecting seemingly unconnected intranets with potent horizontal software capabilities. Open ecosystems and a linked, interoperable platform design are essential for the Internet of Things. The new IoT entities are smart things and cyber-physical systems, also referred to as "things." These are commonplace items that have been improved with microcontrollers, optical and radio transceivers, sensors, actuators, and protocol stacks appropriate for communication in confined contexts with constrained target hardware resources. allowing them to gather environmental data, take appropriate action on it, and function as a conduit for the real world. These items can be placed in the environment or worn by people. They frequently have strict low-cost requirements and are incredibly confined, having little usable memory and energy reserves. The essential criteria for enhancing the initial IoT data and turning it into usable information are data storage, processing, and analytics [67].

2.2 WHAT IS IoT

The world around us is becoming more innovative and responsive because of the Internet of Things, which is fusing the digital and physical worlds [69]. We can make everything a part of the Internet of Things (IoT), from a pill to an airplane, because of the development of incredibly affordable computer chips and the widespread use of wireless networks. The Internet of Things, often known as IoT, is the term used to describe the billions of physical objects that are now linked to the internet and are gathering and exchanging data. The other definition of IoT is sensors and actuators embedded in physical objects linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet [68]. It is possible for gadgets that would otherwise be stupid to transmit real-time data without engaging a person by connecting all these various things and attaching sensors to them.

2.3 HISTORY OF IoT

When a group of college students attempted to modify a Coca-Cola vending machine so that its contents could be tracked remotely in the 1980s, the concept of embedding sensors and intelligence into physical objects first came into existence. However, technology was clumsy and development was slow. The term "Internet of Things" was originally introduced in 1999 by computer scientist Kevin Ashton. Ashton campaigned for the addition of radio-frequency identification (RFID) chips to products during his time at Procter & Gamble so that they could be followed throughout a supply chain. Public interest in IoT technology began to rise over the course of the ensuing decade as more connected devices hit the market. The first smart refrigerator was presented by LG in 2000, the first iPhone was made available in 2007, and by 2008, there were more connected devices than there were people on the planet. Google started developing autonomous vehicles in 2009, and in 2011 they debuted its Nest smart thermostat, which allowed for remote control of the heating system [70]. At the start of the twenty-first century, the media often discussed the Internet of Things, with several significant events laying the foundation for its future. In 2008, Switzerland hosted the International Conference on the Internet of Things. There are already about 27 billion linked gadgets to the Internet of Things; by 2030, scientists predict there will be over 100 billion connected devices [71].

2.4 HOW IoT WORKS

A vast network of linked objects makes up the Internet of things. Huge volumes of information on how these devices work and the information they hold are sent and collected by these devices. Large cloud servers throughout the world receive this data. The cloud delivers the appropriate commands based on the data it has received. Sensors are built into Internet of Things devices. These sensors can sense their immediate environment. The information is kept on the devices in the form of data. Appliances, including cell phones, coffee makers, microwaves, geysers, fire alarms, air conditioners, vehicles, and more, are included in this category.

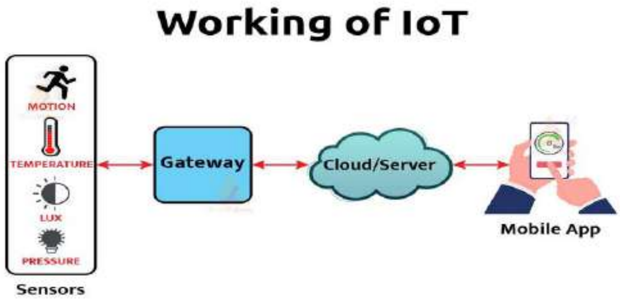


Figure 2.1: IoT working process.

These gadgets' sensors continuously transmit information about their surroundings and how well they are functioning. IoT acts as a platform for dumping all the data that these devices have gathered. Extensive databases and cloud servers are part of the IoT platform. The IoT platform uses the data. It analyses and integrates the data. The platform also thoroughly analyzes the data to glean pertinent information. Based on the information supplied, the platform then returns instructions [72].

2.4.1 COMPONENTS OF IoT

IoT has four components that describe the functioning of most IoT systems:

Sensors/Devices: These gadgets converse with the real world. They collect and preserve the information that is influenced by outside factors. A sensor detects and records environmental changes. Sensors are highly useful for Internet of Things applications because of this characteristic.

Connectivity: Cloud servers are used to process sensor data. But in order to achieve that, they need platforms. Through connection, every IoT device is connected, including sensors, routers, gateways, user apps, and platforms. Cellular networks like LTE or 5G as well as Wi-Fi, Bluetooth, ZigBee, and others may be used to carry large amounts of data. Selecting the appropriate communication channel is crucial since it enables us to govern the entire IoT system.

Data Processing: All of the data is transferred to the platform, where it is processed to provide the necessary outputs, and then it is returned back. The analysis must go fast for the best results. In other words, data analysis is necessary. This is the IoT technology phase that is most important.

User Interface: This is the final action. Due to the variety of duties or goals each IoT device must do, each one has a distinct interface [72]. This stage, which is near to the user, provides the output consumer's view on their screens.

2.5 REQUIREMENTS

We are surrounded by intelligent gadgets driven by the hyper-connected Internet of Things (IoT), and this trend will only accelerate. Every sector is looking for innovative ways to leverage device-enabled data to enhance both the well-being of its equipment and the lives of its consumers. The potential for IoT to alter companies and society is expanding along with the number of devices. Devices are becoming more and more widespread in our lives thanks to the hyper-connected Internet of Things (IoT), and this trend will only accelerate. Every sector of the economy is looking for innovative ways to employ device-enabled data to enhance both the welfare of their customers and the health of their equipment. The potential for the Internet of Things (IoT) to transform businesses and society is expanding along with the number of devices [73].

Edge computing/analytics: Sensors must collect data and perform real-time analysis. It enables quick reaction to sudden change, such as an autonomous vehicle identifying a medical equipment defect or detecting a grocery store's freezer compressor failure.

Data ingestion and stream processing: For preparing the data for use by cloud-based analysis platforms, procedures must be in place for collecting information from various devices and sensors.

Device management: Companies must ensure their IoT devices are set up securely, communicate effectively, and can be upgraded using quick and flexible methods.

Cold path and advanced analytics: Sophisticated analytics and cold path. Cost reductions and new product and business model insights should come from deep diving into IoT data.

Enterprise integration with business systems: To analyze device data, IoT insights need to be sent to corporate systems and given reference metadata [74].

2.6 NETWORK PROTOCOL

In order to link devices across a network, IoT network protocols are utilized. Usually, these protocols are applied when using the internet. Here are a few illustrations of several IoT network protocols.

Wi-Fi: Within a limited area, Wi-Fi links nearby devices to the internet. Making a Wi-Fi hotspot is an additional way to utilize the network. By transmitting a signal, mobile phones or PCs may connect to the internet wirelessly or across a wired network with other devices. Wi-Fi works with radio waves that send information at specific frequencies, such the 2.4 GHz or 5 GHz bands. These frequency bands also provide a variety of channels for usage by different wireless devices, avoiding wireless networks from being overloaded. The normal range of a Wi-Fi connection is 100 meters. The 10 to 35 meter range is the most usual. The environment and whether it offers internal or external coverage affect the Wi-Fi connection's range and speed.

Bluetooth: The 2.4 GHz ISM frequency spectrum is used by standard Bluetooth technology, and packets are delivered to one of the 79 channels. However, the most recent Bluetooth 4.0 specification provides 40 channels and a 2 MHz bandwidth. It ensures a 3 Mb/s maximum data transfer rate. However, it has a sizable user base due to its incorporation into modern mobile devices, such as wireless headphones and smartphones and tablets, to mention a few.

ZigBee: It is a reasonably basic packet data transmission protocol frequently used in low-power gadgets like sensors and microcontrollers. Additionally, it grows well to thousands of nodes. Unsurprisingly, numerous vendors provide products that enable the self-assembly and self-healing grid topology model, an open standard for ZigBee. Its characteristics, however, barely match Bluetooth, which is more widely used. It offers a more extensive communication range. ZigBee can reach 200 meters, has lower power consumption, low data range, and excellent security.

Z-Wave: IoT protocol Z-Wave is becoming more and more well-liked. It is an IoT home application-focused wireless radio frequency (RF) communication technology. It uses the radiofrequency 800-900MHz to function. On the other hand, Zigbee uses 2.4GHz, a fundamental Wi-Fi frequency. Because Z-Wave operates inside its range, it seldom encounters serious interference issues

LoRaWan: The LoRaWAN IoT protocol is a media access control (MAC) protocol. Through a long-range wireless connection, LoRaWAN enables low-powered devices to speak directly with web-connected apps. It is based on LoRa or FSK modulation for usage in ISM radio bands (industrial, scientific, and medical) [75]. It might also be linked to the second and third levels of the OSI model.

2.7 5G AND IoT

5G's faster, more dependable, and more secure connectivity enables the growth of everything from self-driving vehicles to smart grids for renewable energy to AI-enabled robots on production floors. The huge IoT ecosystem released can accommodate billions of linked devices with the right speed, latency, and cost trade-offs. The 3rd Generation Partnership Project developed and standardized 5G after the International Telecommunications Union (ITU) established the minimum requirements for new technologies [81]. The speed with which an IoT device can connect to other IoT devices, mobile phones and tablets, software in the form of its app or website, and other IoT devices ultimately decides whether or not it will be commercially viable. With 5G, data transfer speeds will significantly increase. The predicted speed of 5G networks is 10 times faster than that of current LTE networks. Thanks to this increase in speed, IoT devices will be able to communicate and exchange data more swiftly than previously [82].

2.8 APPLICATION

IoT technologies have a wide range of applications since they can be applied to almost any adaptive item that may offer important information about its functioning, the success of an endeavor, or even the environmental conditions we need to remotely monitor and control.

Smart Homes: Smart homes are among the most great and beneficial IoT applications since they considerably increase both convenience and home security. While there are additional levels, the ideal IoT application for smart homes combines intelligent utility systems with entertainment. “The set-top box that enables remote TV show recording, the electricity meter with an Internet of Things device that provides insights into your daily water usage, the automatic lighting systems, sophisticated locking systems, and connected surveillance systems are a few examples of devices that fit into this concept of smart homes.” We can be certain that as the Internet of Things evolves, the majority of devices will become more capable, enhancing home security [76].

Smart City: Smart cities should have technologies that can connect to the internet and the people who live there. And we can confidently state that we're working to make this ideal a reality. Infrastructural needs and specific vital issues, such as traffic management, waste management, water distribution, electricity management, and more, are being created to use linked technologies. All these contribute to greater convenience by removing some daily obstacles people experience [76].

Traffic monitoring: The notion of smart cities can be enhanced by the Internet of Things by helping to control automobile traffic in big cities. When we use our mobile phones as sensors to gather and share data from our automobiles via apps like Waze or Google Maps, we leverage the Internet of Things to keep us informed and to contribute to traffic monitoring. These applications provide information on the various routes' conditions as well as statistics on their distances, expected arrival times, and multiple routes to the same location.

Self-driven Cars: Because we are dealing with human lives on the roads, we must ensure that technology has everything it needs to improve passenger and road user safety. The car uses a variety of integrated sensors and cloud and internet-connected technologies to continually create data and send it to the cloud for machine learning-based decision-making. We are already witnessing one of the most palatable uses of IoT, even if it takes some more time for the technology to develop fully and for countries to adjust their laws and regulations [77].

Fleet management: It is simpler to establish an effective link between fleet vehicles, their management, and drivers when the vehicles have sensors attached. Both the driver and the manager/owner may use the software that collects, analyzes, and organizes the data to offer a wealth of information about the status, operation, and requirements of the vehicle. Even when the driver is not aware of them, maintenance problems might be immediately notified.

Farming: Agriculture is one sector that stands to benefit the most from the Internet of Things. With all the technological improvements in agricultural equipment, the future is undoubtedly promising. For example, drip irrigation, crop pattern analysis, water distribution, drone farm monitoring, and other uses, tools are being developed.

Wearables: Wearable technology was one of the first industries to use the IoT, and it is a key component of IoT applications. Fit Bits, heart rate monitors, and smartwatches are widely used nowadays. One of the less popular wearables is the Guardian glucose monitor. The device was developed to assist people with diabetes. Under the skin, a small electrode known as a glucose sensor analyzes the body's glucose levels and sends the information to a monitoring device via radio frequency.

Smart Pollution Control: In most places worldwide, pollution is the central issue. Sometimes it's hard to tell if we're breathing in oxygen or pollution! IoT can play a significant role in this case in reducing pollution levels to bearable levels. It may be accomplished by gathering information on urban pollutants, such as car emissions, pollen levels, airflow direction, weather, traffic volume, etc., utilizing a variety of sensors in conjunction with IoT. With this data, machine learning algorithms can predict pollution levels in various city neighborhoods, letting policymakers know where the issues will arise. Once it is significantly safer, they may strive to manage pollution levels.

Water/ Waste Management: Water recycling utilizing water treatment units is becoming popular in many places. We can address this problem with the aid of cutting-edge sensor technology and Internet of Things applications. We may look at how much wastewater is produced, how much is consumed in a certain area, and how the waste production varies over time using an IoT application. In addition to other things, authorities will be able to predict how much rubbish will be generated in a certain region, how to handle it, when to properly clean it away, and how to assess data for future planning.

Health: With wearables or sensors attached to a patient, doctors can check on them outside of the hospital. The Internet of Things improves patient care and prevents fatal occurrences in high-risk patients by monitoring specific metrics and sending automated warnings based on their vital signs. IoT technology can also be used in hospital beds to make smart beds with sensors that can monitor vital signs like blood pressure, body temperature, and oximeter, among other things.

Hospitality and Tourism: Numerous exchanges can be automated using electronic keys delivered to each visitor's mobile device. Electronic keys enable automatic check-out procedures that disable door functionality, provide details about available rooms, and even delegate housekeeping duties to maintenance staff. Therefore, using integrated applications and the Internet of Things, it is simple to manage activities such as tracking the location of guests, sending offers or information about exciting activities, executing orders for room service or delivery, automatically charging room accounts, and requesting personal hygiene supplies.

Smart grid and energy saving: For defect detection, decision-making, and fault repair, a bidirectional communication channel between the service provider firm and the end user can be established and give information of immense value. Additionally, it provides users with helpful information on their consumption habits and the most effective strategies to reduce or modify their energy usage.

Retail IoT: Similar to the industrial sector, the retail industry may use internet of things technologies to find savings, efficiency, and innovation. Among the many things retail IoT can do are enhance the customer experience, track products accurately and in real-time, optimize staffing plans, and manage inventories more effectively overall. To better inform consumer strategy, retailers may use the IoT to track customer buying behaviors and discover their purchase histories, trends, and location data.

IoT-Connected Factories: In order to set strategic goals and boost efficiency, smart factories employ IoT technology, also known as the Industrial Internet of Things, to gather data on industrial equipment and operations. To improve analytics, sensors are linked to machinery and industrial tools. To protect profits and improve the efficiency of the supply chain, this technology could help manufacturers reduce energy use, improve asset monitoring, and find equipment problems early [78][79][80].

Chapter-3
Antenna and Propagation

3.1 INTRODUCTION

One of the most important components of wireless systems is the antenna. The system requirements and performance of an antenna system may be considerably lowered and improved, respectively. Radar, navigation, landing systems, direct broadcast TV, satellite communications, mobile communications, and many more types of systems are included in the wireless systems. For radio telescopes, an antenna may be 100 meters by 100 meters in size, while it may be a few millimeters for built-in phones. They all have a significant impact on science and daily life. We currently profit much from wireless, and antennas have made substantial contributions that should not be undervalued. "An antenna is an electromagnetic transducer that changes guided waves inside transmission lines into radiated free-space waves and free-space waves into guided waves when receiving."

Thomas Edison created the first mobile communication system in 1885 using wireless telegraphs between trains and stations [83]. The trolley wires carried telegraph signals, electro-statically connected with a metal plate on the train's roof. In 1901, Edison also tested communication on a moving car [84] by mounting a large, cylindrical antenna on the vehicle's roof. Guglielmo Marconi invented wireless telegraphy on ships in 1898. It used long vertical wire antennas in various configurations, including T, inverted L, and umbrella shapes. In 1910, portable equipment made its debut [85].

In the 1920s, wire antennas were firmly established, and in the 1950s, modern microwave antenna design and technology were widespread. The groundbreaking advancements in semiconductor integrated circuits, which were first credited to the Cold War defense industry but were primarily carried over into the commercial equipment sector, developed a new age of antenna technology in the 1960s. Both World Wars created a demand for enhanced antenna design and a spike in technological advancement [86]. The need made it possible for designers to remodel, recreate, and change well-known antenna types into radiating structures that were less clumsy, lighter, cheaper, and easier to manufacture, suitable with the recently developed integrated electronic packages. The development of printed antenna technology, which supports multifunction antenna devices, has received the most attention [87]. In many mobile systems, both in base stations and mobile terminals, where tiny, compact, and lightweight antennas are required, planar antennas, derived initially from printed antennas, have been employed. The most crucial driver of antenna technology nowadays is communications, especially mobile communication systems, according to some of the critical elements that have progressively affected antenna design in this century [88] and do so today. Other key elements that substantially impact the development of various unique antenna systems include the rollout of new wireless mobile systems and the integration of mobile systems with IP networks.

A radio antenna is "a generally metallic device (like a rod or wire) for transmitting or receiving radio waves," according to Webster's Dictionary. The antenna or aerial is described as "a method for transmitting or receiving radio waves" in the IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983). In other words, as seen in Figure 3.1, the antenna serves as a bridge between free space and a guiding device. It can be in the shape of a coaxial line or hollow pipe (waveguide). From the transmitting source to the antenna or from the antenna to the receiver, electromagnetic energy is transferred via a guiding mechanism or transmission line. In the first instance, we have a sending antenna, and in the second, a receiving antenna.

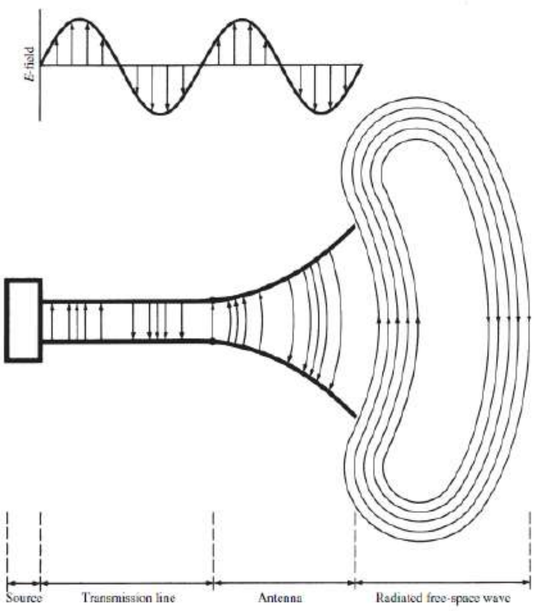


Figure 3.1: Antenna as a transition device [89].

3.2 ANTENNA WORKING PRINCIPLE

The antenna has the capability of signal broadcasting and receiving. A metal conductor is the main component of an antenna, which carries radio frequency (RF) waves between two places in space. When a voltage is delivered to a transmitting antenna, it creates radio signals that are then transmitted to a receiving antenna and decoded into informational electrical energy [90].

The purpose of a radio antenna is to convert electricity sent to it in the form of an electromagnetic wave using an alternating current signal with a radio frequency. This electromagnetic pulse can pass over the distance between a receiving antenna and a radio transmitter. The electromagnetic wave is changed back into a radio frequency signal at the receiving end so that it may be applied to the receiver's input. A radio antenna's function is to transform the power given to it in the form of an alternating current signal with a radio frequency into an electromagnetic wave. This electromagnetic wave can pass through the area between a radio antenna that is broadcasting and one that is receiving. The electromagnetic wave is changed back into a radio frequency signal at the receiving end so that it may be applied to the receiver's input.

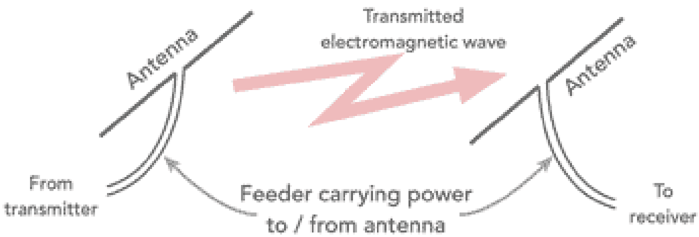


Figure 3.2: Antenna working principle [91].

This enables a radio antenna, which launches a signal in the form of an electromagnetic wave, to receive power. Similarly, when an electromagnetic wave strikes an antenna, it is transformed into a radio frequency signal that may be transmitted to the input of the receiving apparatus. Maxwell’s equations may describe the fundamental physics underlying how antennas function. They talk about how current or charges moving down the antenna produce electromagnetic waves. When operating an antenna, it may be possible to see a point charge that oscillates in time with the radio frequency signal in a more qualitative way.

The oscillation of the charge will cause the resultant electric field to change, and this modifying electric field will result in a displacement current. Ampere's Law will then cause this current to generate a magnetic field. The fluctuations of the electric and magnetic fields co-occur because the oscillation of the charge alters them as well. Faraday's law states that an electric field will be produced by a fluctuating magnetic field. The cycle will then repeat as this electric field generates another magnetic field. Electric and magnetic field waves make up the electromagnetic waves that travel out from the original point charge. The energy of the initial oscillating point charge is transformed into electromagnetic wave energy, or put another way, the power entering the antenna is transformed into electromagnetic wave energy. Additionally, it is obvious that the antenna's current component is what generates the electromagnetic waves that are transmitted [91].

3.3 TYPES OF ANTENNA

Antennas can be classified in various ways. Many different antenna types are used in radio systems with specialized properties for particular applications. The list below groups antennas under common operating principles, following the way antennas, are classified [92].

3.3.1 THE PHYSICAL STRUCTURE OF THE ANTENNA

The types of antennas, according to the physical structure are some of them are described below-

3.3.1.1 WIRE ANTENNA

Wire antennas are well known to the general public because they may be seen on vehicles, buildings, ships, airplanes, and spacecraft. Figure 3.3 illustrates three wire antennas: a straight wire (dipole), a loop, and a helix. Not all loop antennas are circular. They might be shaped like a square, rectangle, ellipse, or any other shape. Due to the circular loop's ease of creation, it is the most popular**.**

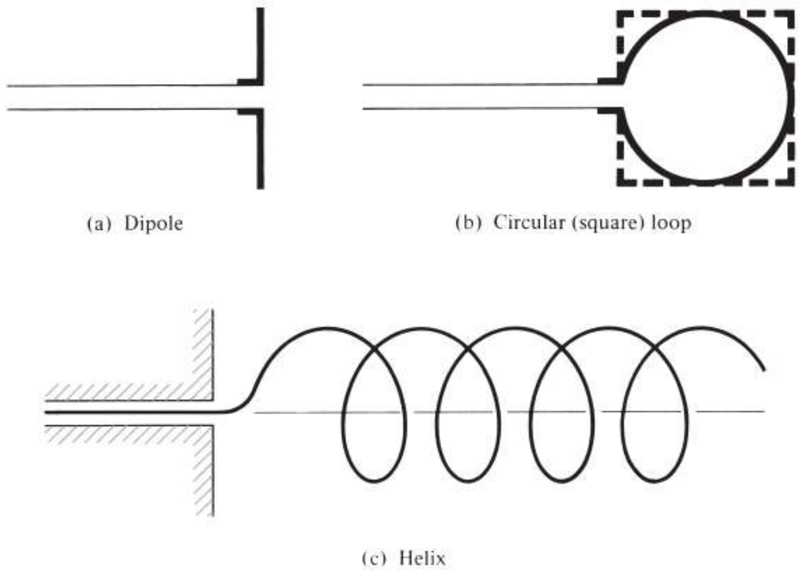


Figure 3.3: Wire antenna configurations [93].

3.3.1.1.1 DIPOLE ANTENNA

Dipole antennas are one of the most basic antenna layouts. A sinusoidal voltage differential exists between two thin metal rods that make up this dipole antenna. Rod lengths are selected so that, at operating frequencies, they have a wavelength of one-fourth their length. They utilize these antennas to create either their own or other antennas. It is straightforward to construct and utilize. Current and frequency pass via the two metallic rods that make up the dipole antenna. An electromagnetic wave is produced by the current and voltage flow, and the radio signals are red. A radiating component in the antenna divides the rods. And uses the transmitter's feeder to take it from the receiver. Through the center, it generates currents. Semi-wave, multiple, fold, non-resonant, and dipole antenna designs are used as RF antennas.

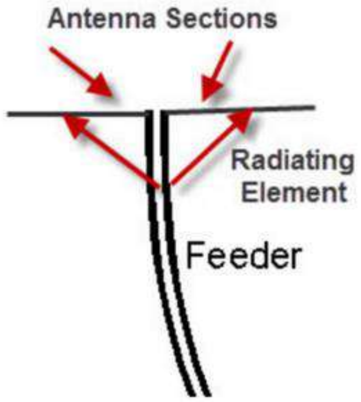


Figure 3.4: Dipole antenna [94].

3.3.1.1.2 SHORT DIPOLE ANTENNA

This type of antenna is the simplest of all antenna forms. The revolving wire of this antenna is open. The shorthand here means "related to the wavelength." As a result, this antenna favors the size of the wire about the operating frequency's wavelength. The size of the dipole antenna on its whole is not considered. The dipole is short if the radiating element's length is less than one-tenth of the wavelength. Two co-linear conductors make up the short dipole antenna. This is a brief separation of the conductor from the feeder.

$$L<\lambda/10$$

Two co-linear conductors make up short dipole antennas. This is a brief separation of the conductor from the feeder. Short dipole antennas rarely provide satisfactory performance. Most power entering the antenna is lost as heat and resistance rapidly rise [95].

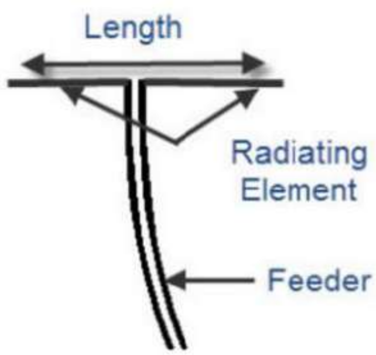


Figure 3.5: Short Dipole Antenna [95].

3.3.1.1.3 MONOPOLE ANTENNA

A monopole antenna is made of one conductor, often erected over the ground or artificially conducting surface. The feed line from the transmitter or receiver is linked to the conductor on one side and the ground or an artificial ground plane on the other. The radio waves that are reflected off the ground plane appear to come from an image antenna that is buried under the surface, giving the monopole antenna a radiation pattern similar to the upper half of a corresponding dipole antenna. The antenna has double the gain of a comparable dipole without considering ground plane losses since all of the radiation from the analogous dipole is focused in a half-space [96][97].

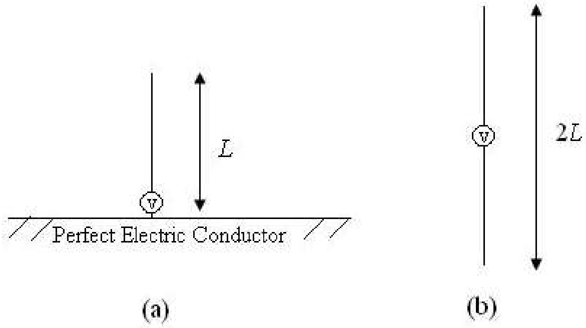


Figure 3.6: (a) Monopole above a PEC and (b) the equivalent source in free space [98].

3.3.1.1.4 LOOP ANTENNA

Loop antennas are comparable to Dipole and Monopole antennas. A loop antenna's fundamental property is unaffected by its form. Because it is straightforward and quick to construct, the form of the loop antenna might be circular, elliptical, rectangular, etc. This frequency is roughly 3 GHz and is commonly utilized in communication networks. In microwave bands, these antennas are also employed as electromagnetic field probes. The loop antenna's effectiveness is dependent on its circumference. Monopole and dipole antennas are comparable. These antennas are divided into two more categories. Depending on the loop's circumference, electrically tiny and enormous.

Electrically small loop antenna———> Circumference $\leq \lambda/10$

Electrically large loop antenna———> Circumference $\approx \lambda$

Electrically tiny loops with a single turn have a lower radiation resistance than their loss resistance. More radiation resistance turns can be added to smaller loop antennas to increase their performance. Even though they have poorer efficiency, multi-turn loops have a higher radiation resistance. Because of this, they receive antennas where loss is not required and typically employ tiny loop antennas. Since they are not very efficient, small loops are not employed as transmit antennas. Single-turn electrically small loops have a lower radiation resistance than their loss resistance. Smaller loop antennas' performance can be improved by adding more radiation resistance turns. Multi-turn loops have a stronger radiation resistance while having a lower efficiency. As a result, small loop antennas are frequently used in receiving antennas where loss is not necessary. Small loops are not used as transmit antennas since they are not particularly effective [99].

Figure 3.7: Loop Antenna [100].

3.3.1.2 APERTURE ANTENNA

Aperture antennas are defined as antennas with an aperture at the end. An antenna's aperture is the region where electromagnetic field effects can be used to generate electricity. The waveguide is the most remarkable illustration of this antenna. The aperture, in this case, might be rectangular, square, or round. It is an ortho-rectified multiband antenna. It is constructed using a giant loop wrapped around a collection of microstrip transmission lines per the Wilson Leaky-tube design. According to the first Hata's square law, this design produces a compact omnidirectional pattern with good gain and elevation patterns.

In contrast to tighter apertures, the gain of a wider aperture is substantial. The available electromagnetic field density and available voltage surrounding the antenna may be used to calculate the effective aperture of the antenna, which is a circle-shaped area around the antenna. The signal power emitted in a single direction determines this antenna size [101].

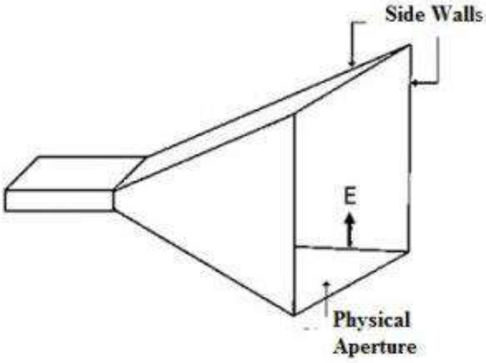


Figure 3.8: Aperture antenna [101].

3.3.1.3 REFLECTOR ANTENNA

An antenna reflector is a tool that reflects electromagnetic waves. To reroute the radio frequency energy, Antenna reflectors can be either independent or incorporated into an antenna assembly. Reflector antennas are frequently employed for high-gain applications in radar imaging, deep space communications, ground communications, and satellite communications. The significant advantages of reflector antennas over other antenna types are that they give high gain and broad bandwidth capabilities at a reduced cost. The parabolic reflector is the type of antenna that is most frequently employed for high-gain applications. They transform the spherical wave light from the feed into a plane wave in the far field through improved gain, smaller beam widths, and low side lobe levels. The feed mechanism is the sole factor limiting the bandwidth of the parabolic reflector antenna because it is frequency-independent [102].

Figure 3.9: Reflector Antenna [103].

3.3.1.4 LENS ANTENNA

A lens antenna is a type of microwave antenna that employs refraction to concentrate and bend radio waves; much like an optical lens does for light, using a curved piece of microwave-transparent material. The typical setup comprises a tiny feed antenna, like a patch antenna or horn antenna, that emits radio waves, together with a piece of dielectric or composite material in front that serves as a converging lens to focus the radio waves into a beam. On the other hand, the lens on the receiving antenna focuses the radio waves on the feed antenna, transforming them into electric currents and sending them to a radio receiver. To produce more intricate radiation patterns, they can also be fed by a group of feed antennas collectively referred to as a focal plane array. The lens antenna's working frequency range starts at 1 GHz but is mainly utilized above 3 GHz [104].

Figure 3.10: Lens Antenna [105].

3.3.1.5 MICROSTRIP ANTENNA

A patch antenna is an antenna that is made by removing conductive material from a dielectric surface in a certain area. The ground plane, which serves as the foundation for the whole construction, is where the dielectric material is installed. Feed wires connecting through the patch are also used to excite the antenna. It is also referred to as a microstrip or printed antenna since it is constructed on a printed circuit board using microstrip technology [106].

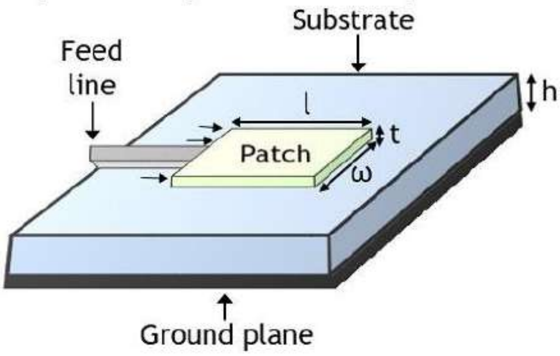


Figure 3.11: Micro strip antenna.

3.3.1.6 ARRAY ANTENNA

An antenna array is a collection of linked antennas placed regularly to form one large antenna that may emit radiation in patterns that aren't possible with a single antenna when used individually. Many antenna arrays have thousands of different antennas, such as military phased array radars. They offer a remedy for the issues brought on by single antennas. For example, the dipole antenna offers better direction control than an isotropic antenna, but direction control may diminish as the dipole's length rises. With a dual radiator setup, more control and flexibility can be quickly restored for beam direction. An antenna array can produce a smaller radio wave beam with a higher gain (directivity) than a single element could. The gain and beam width increase with the number of individual antenna elements utilized [107].

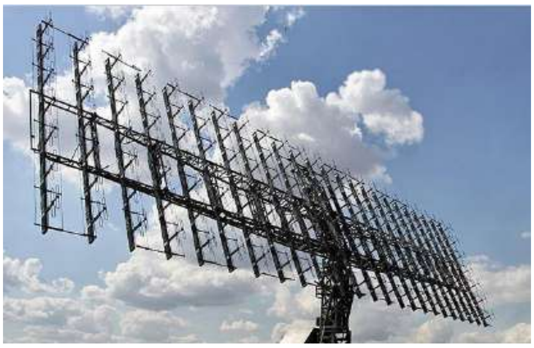


Figure 3.12: Antenna Array [108].

3.3.2 THE FREQUENCY RANGE OF OPERATION OF THE ANTENNA

The various antenna types according to operating frequency are listed below.

3.3.2.1 VERY LOW-FREQUENCY ANTENNA

The antenna operates in the low-frequency range from 3–30 kHz and is known as the Very low-frequency antenna. Geophysicists employ naturally occurring signals in the VLF band to locate long-distance lightning and study atmospheric phenomena like the aurora. Whistler measurements are used to deduce the magnetosphere's physical characteristics. The military uses powerful VLF transmitters to connect with its soldiers worldwide. Long range, excellent dependability, and the expectation that communications using VLF frequencies will be less interrupted by nuclear explosions than those using higher frequencies in a nuclear conflict are all benefits of using VLF frequencies. The military uses VLF to communicate with submarines close to the surface because it can penetrate saltwater, whereas ELF frequencies are utilized for submarines that are deeply submerged.

Figure 3.13: Very low frequency antenna [109].

3.3.2.2 LOW-FREQUENCY ANTENNA

The low-frequency antenna is a device that functions in the low-frequency region of 30-300 kHz. Before picking up low-frequency ground waves, a transmitter antenna can be up to 2,000 kilometers away. The attenuation of signal strength with distance brought on by ground absorption is weaker at lower frequencies than to higher frequencies. Low-frequency waves can occasionally travel considerable distances by reflecting from the ionosphere, however it happens less frequently than at higher frequencies. Skywave or "skip" propagation is the name of this phenomenon. Reflection takes happen in the ionospheric E or F layer. At a distance of more than 300 kilometers from the transmitting antenna, skywave signals can be picked up.

Figure 3.14: Low Frequency antenna [110].

3.3.2.3 MEDIUM-FREQUENCY ANTENNA

The antenna operates in the frequency range from 300 KHz–3 MHz and is known as the Medium-frequency antenna. AM broadcasting is a prominent usage of these frequencies; These frequencies are often used for AM transmission; in Europe and North America, AM radio stations are given frequencies in the medium wave broadcast band that range from 526.5 kHz to 1606.5 kHz [111] and from 525 kHz to 1705 kHz [112]. The 120-meter band, mainly utilized in tropical regions, spans 2300 to 2495 kHz frequencies, and some nations also permit broadcasting in this range. One hundred twenty meters is typically regarded as one of the shortwave bands even though these frequencies are in the middle range. Between 1600 and 2850 kHz, various coast guard and other ship-to-shore frequencies are in operation. These include, for instance, the US Coastguard on 2670 kHz, Madeira on 2843 kHz, Stornoway Coastguard on 1743 kHz, and the French MRCC on 1696 kHz and 2677 kHz. Weather Fax information is transmitted on 2618.5 kHz by RN Northwood in England. For marine and aviation navigation, non-directional radio beacons (NDBs) operate from 190 to 435 kHz, which crosses over from the LF into the lower portion of the MF band.

Figure 3.15: Medium Frequency Antenna [113].

3.3.2.4 HIGH-FREQUENCY ANTENNA

The antenna operates in the frequency range from 3-30MHz and is known as the High-frequency antenna. In this band, wire dipoles and rhombic antennas are most frequently used. In the higher frequencies, multi element dipole antennas like the Yagi, quad, and log-periodic antennas are used. Robust shortwave radio stations frequently use large wire curtain arrays. Skywave antennas are often composed of bottom-fed loops or horizontal dipoles, both of which output horizontally polarized waves. Amateur radio operators like the direct, long-distance connections and the "thrill factor" that comes from making contacts under unpredictable settings, which makes the high-frequency band particularly popular. This set of frequencies is used for international shortwave broadcasting as well as a seemingly decreasing number of "utility" users (marine, aviation, military, and diplomatic interests), who have recently switched to less unstable communication methods but may still keep HF stations after the switch-over for backup purposes.

Figure 3.16: High Frequency antenna [114].

3.3.2.5 VERY HIGH-FREQUENCY ANTENNA

The antenna operates in the frequency range of 30-300MHz and is a very high-frequency antenna. VHF is the first frequency band with wavelengths narrow enough for feasible antennas to fit on automobiles and portable gadgets; a quarter-wave whip antenna at VHF frequencies is between 25 cm and 2.5 meters long. Therefore, two-way radios in cars, planes, portable transceivers, and walkie-talkies operate in the VHF and UHF frequency bands. While base stations often utilize more enormous fiberglass whips or collinear arrays of vertical dipoles, portable radios typically use whips or rubber ducky antennas.

Figure 3.17: Very high-frequency antenna [115].

3.3.2.6 ULTRA HIGH-FREQUENCY ANTENNA

The Ultra High-Frequency Antenna is a frequency range antenna that runs between 300MHz and 3GHz. UHF frequencies are utilized for cordless and mobile phones as well as two-way land mobile radio systems, such walkie-talkies and two-way vehicle radios. Because UHF wavelengths are so short, viable transmitting antennas may be mounted on portable and mobile equipment. Urban regions' need for more free-to-air television channels was met by UHF television transmission. The usage of mobile phones, trunked radio, and land mobile radio systems now takes up a large portion of the bandwidth. Digital television still uses UHF channels.

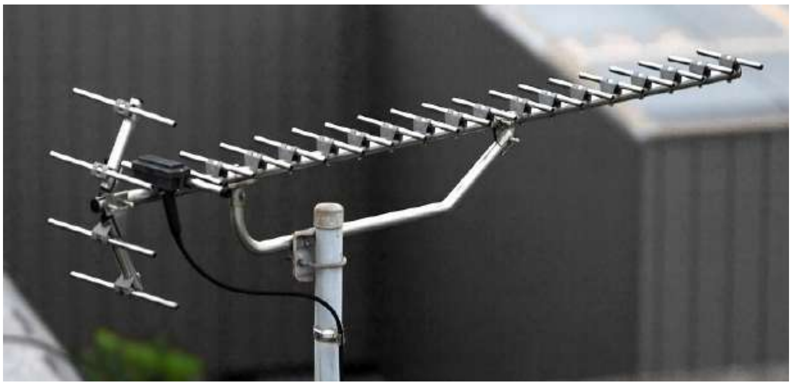


Figure 3.18: Ultra High-frequency antenna [116].

3.3.2.7 SUPER HIGH-FREQUENCY ANTENNA

The antenna operates in the frequency range from 3-30GHz and is known as the Super high-frequency antenna. SHF waves are commonly employed for wireless applications because their wavelength is short enough for practical transmitting antennas to be readily placed on portable devices. For instance, the length of a quarter-wave whip antenna for the SHF band ranges from 25 to 2.5 cm. For uses like wireless gadgets and telephones, omnidirectional antennas that can fit inside the device's casing have been created. The printed inverted F antenna (PIFA), made of a copper foil monopole antenna bent into an L shape on the printed circuit board within the device, is the primary antenna utilized for these gadgets.

Figure 3.19: Super high-frequency antenna [117]

3.3.2.8 EXTREMELY HIGH-FREQUENCY ANTENNA

In an important new use of millimeter waves, the most recent generation of mobile phone networks, 5G networks, employ the precise frequency ranges near the bottom of the band. The antenna operates in the frequency range from 30-300GHz and is known as the Extremely high-frequency antenna. Due to limits in semiconductor and process technology, model capabilities, and low Q factors of passive devices, the design of millimeter-wave circuits and subsystems (such as antennas, power amplifiers, mixers, and oscillators) also poses significant engineering hurdles.

Figure 3.20: Extremely high-frequency antenna [118].

3.4 ANTENNAS BASICS AND PERFORMANCE PARAMETER

To understand an antenna properly, we must first understand some essential parameters. Some are used to design the antenna, and some are used to analyze the antenna's performance and characteristics. Those parameters are given below.

3.4.1 FREQUENCY

A recurring event's frequency is measured by how many times it occurs in a unit of time. It is also sometimes called "temporal frequency" to stress the difference between "spatial frequency" and "ordinary frequency" to underline the contrast to "angular frequency." Hertz is the frequency's SI unit. The letter λ symbolizes it. One hertz means that a wave's cycle took one second to complete. The cyclic process is typically expressed in revolutions per second or hertz. The parameter of frequency is what describes oscillatory and vibration phenomena, such as mechanical vibration, sound signals, light, frequency waves, etc. The time a wave needs to complete one oscillation is what is meant by the term "period," which is inversely related to frequency.

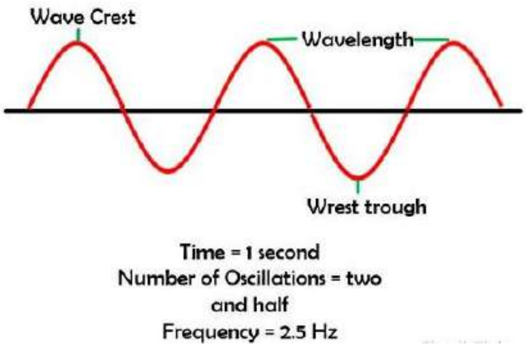


Figure 3.21: Frequency.

3.4.2 WAVELENGTH

The distance over which a periodic wave's form repeats is known as its wavelength [119]. The separation between neighboring wave points corresponds to the same phase, such as two adjacent crests, troughs, or zero crossings. It is a property of traveling, standing, and other spatial wave patterns. The spatial frequency is the reciprocal of the wavelength. Wavelength is usually denoted by the Greek letter lambda (λ). The term wavelength is also occasionally used to refer to modulated waves, their sinusoidal envelopes, or waves created by the interference of several sinusoids [120].

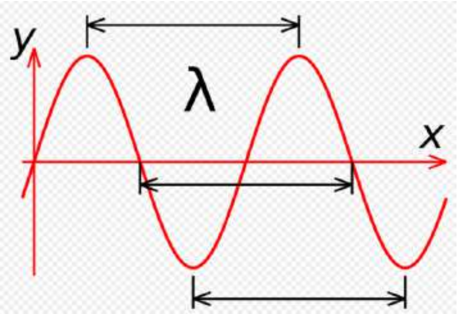


Figure 3.22: Wavelength.

3.4.3 BANDWIDTH

"The range of frequencies over which the antenna's performance, about some attribute, complies with a set standard" defines an antenna's bandwidth. The bandwidth [121] is the range of frequencies on either side of a center frequency, which is typically the resonance frequency for a dipole, where the properties of the antenna, such as input impedance, pattern, beamwidth, polarization, side lobe level, gain, beam direction, and radiation efficiency, are reasonably close to those at the center frequency.

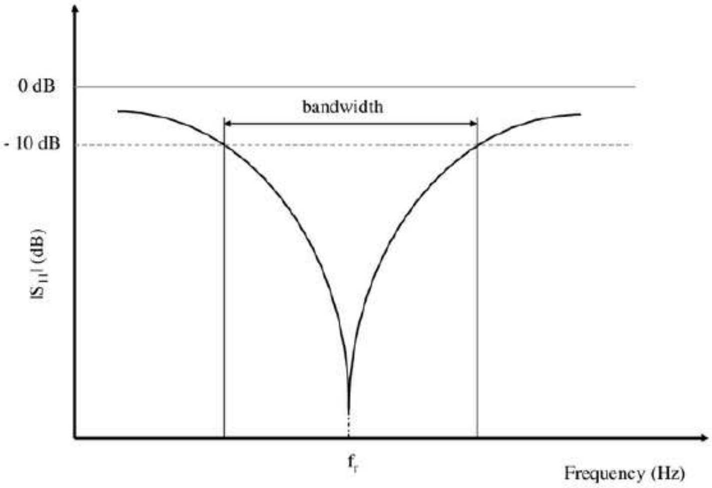


Figure 3.23: Bandwidth.

3.4.4 PERCENTAGE BANDWIDTH

The percentage bandwidth calculation is straightforward and estimates how much frequency variation a system or component can tolerate. As frequency increases, the total bandwidth as a component naturally increases, whereas the percent bandwidth decreases. In wideband applications, percent bandwidth has little application. A bandwidth ratio of 3:1 equates to a percent bandwidth of 100%. The 100 to 200 percent range is compressed to contain all the more excellent ratios up to infinity. We can find the percentage bandwidth by the flowing equation. Here "BW" is the *total* bandwidth, and FC is the center frequency.

$$BW\% = \frac{BW}{F_C}$$

3.4.5 REFLECTION COEFFICIENT (S11)

An impedance discontinuity in the transmission medium might reflect some or all of a wave, according to a characteristic known as the reflection coefficient. It is equivalent to the phasor representation of the ratio of the incident wave's amplitude to that of the reflected wave. It is denoted by the symbol Γ [122]. Reflection coefficient Γ defined as,

$$\Gamma = {V_{Ref}}/{V_{Fwd}}$$

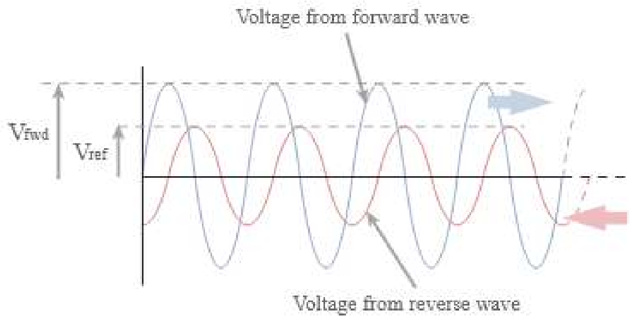


Figure 3.24: Reflection coefficient.

3.4.6 VOLTAGE STANDING WAVE RATIO (VSWR)

In an RF component or system, the voltage standing wave ratio (VSWR), also called Standing Wave Ratio (SWR), is the proportion between the incident and reflected waves. It establishes the effectiveness of power transmission over a transmission line from a source to a load (or cable). The optimum situation, when the load absorbs all of the power from the source, has a minimum value of VSWR of 1:1 . However, VSWR is rarely found to be 1:1 in real-world applications, and techniques are created to keep the VSWR as near to unity as feasible [123]. It is defined with the below equation where Γ is the reflection coefficient.

$$\text{VSWR}=\frac{1+\Gamma}{1-\Gamma}$$

3.4.7 RADIATION INTENSITY

Radiation intensity in a particular direction is defined as "the power emitted from an antenna per unit solid angle". Radiation intensity is a far-field parameter determined by multiplying the radiation density by the distance squared. It may be written out using mathematical notation as [124],

$$\text{U}=r^2W_{rad}$$

Where,

U is the radiation intensity

r is the radial distance

W_{rad} is the power radiated

3.4.8 BEAMWIDTH

At each of its nodes, an antenna pattern has a range of beam widths. The Half-Power Beamwidth, also known as HPBW, is frequently one of the beam widths. The IEEE defines this beamwidth as follows: "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is the one-half value of the beam." The angular gap between two identical spots on opposing sides of the pattern maximum is meant to be understood as a pattern's beamwidth. An antenna's beamwidth is a crucial performance metric that is frequently used as a trade-off with the quantity of side lobes. The side lobe level increases as beamwidth decreases and vice versa. In addition, the antenna's beamwidth is also used to characterize its resolution capabilities, allowing it to differentiate between two radiating sources or radar targets located near one another [125].

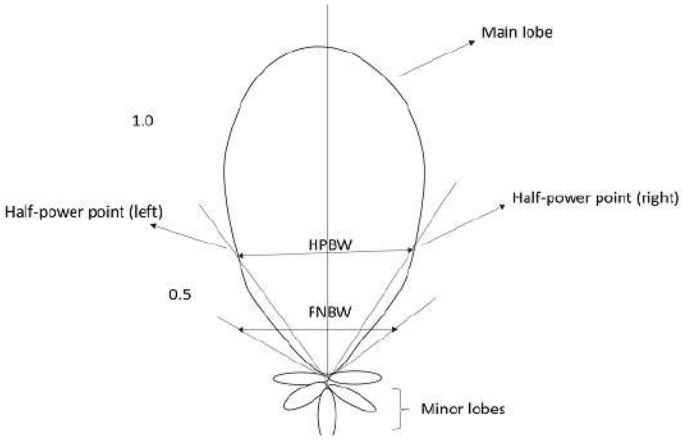


Figure 3.25: Beamwidth.

3.4.9 DIRECTIVITY

An antenna's directivity is described as "the ratio of the radiation intensity from the antenna in a given direction to the radiation intensity averaged across all directions". This ratio is referred to as the radiation intensity ratio. The total power emitted by the antenna is divided by 4π, which is equivalent to the average radiation intensity. If the direction is not given, the direction with the highest possible radiation intensity is assumed to be the correct one. The directivity can be written as [126],

$$D=\frac{4\pi U}{P_{rad}}$$

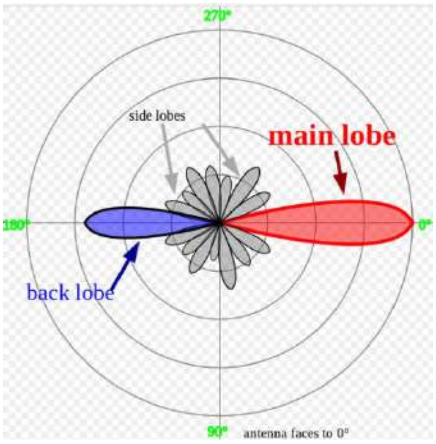


Figure 3.26: Directivity.

3.4.10 GAIN

A performance indicator measured about a reference source is known as the antenna gain. Antenna gain is quantified using the decibels over the isotropic (dBi) system. This system refers to an isotropic antenna, an "ideal" antenna that transmits and consistently receives energy in all directions and has a gain of 0 dBi (Fig. 3.27). The capacity of an antenna to convert input power into radio waves sent in a particular direction is referred to as gain. A transmitting antenna has this capacity. The term "gain" refers to the capacity of a receiving antenna to transform the electromagnetic energy carried by radio waves (which are arriving from a specific direction) into electrical power [127].

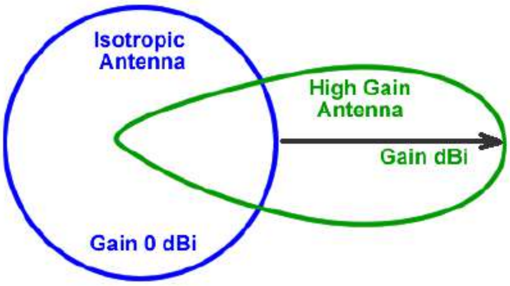


Figure 3.27: Antenna Gain.

3.4.11 RADIATION PATTERN

The fluctuation in the amount of power emitted by an antenna as a function of the direction away from the antenna is referred to as the antenna's radiation pattern. In the distant field of the antenna, this fluctuation in strength may be seen as a function of the signal's angle of arrival [128].

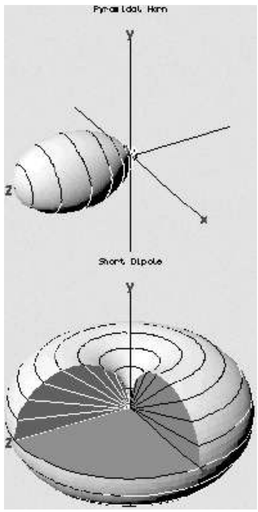


Figure 3.28: Radiation Pattern.

3.4.12 ANTENNA EFFICIENCY

The power provided to the antenna to the power emitted from the antenna determines the efficiency of the antenna. Most of the power at the antenna's input is radiated away by a high-efficiency antenna. Most of the power used by an antenna with low efficiency is lost as internal losses or is reflected away owing to impedance mismatch. An antenna's efficiency remains the same whether it is being used as a broadcast or receive antenna, which is a great feature. So, the ratio of "potential power received from all conceivable angles" may be used to measure antenna efficiency, although that would be more difficult. Just keep in mind that transmit and receive antenna efficiency are equivalent. Because understanding efficiency in terms of power provided vs. power radiated is more spartan, we'll stick with that definition for now. Antenna reciprocity is the name given to this quality of antennas. The antenna efficiency is the antenna's input power ratio to its output power[129].

$$\varepsilon = \frac{P_{Radiated}}{P_{\mathrm{Input}}}$$

Chapter-4
Literature Review and Motivation

4.1 INTRODUCTION

A literature review examines information that has been published in a specific field of study and, on occasion, during a particular time period. A literature review can be a summary of pertinent materials. Still, a literature review often has an organizational purpose in the social sciences and incorporates both summary and synthesis, sometimes within established conceptual categories. Although a literature review could just a list of sources, it frequently follows an organizational framework and involves summary and synthesis. The material in a summary, which is a recap of the main ideas from the source, is reorganized or rearranged in a synthesis. It could give a fresh interpretation of dated facts or merge fresh and obsolete ideas. Or it could explain the field's intellectual history, including major disagreements. The literature review may also appraise the sources and advise the reader on the most topical or relevant, depending on the circumstances [130].

The major purpose of an academic research paper is to generate a fresh argument, and a literature review is typically included in research papers as one of its components. We use the corpus of literature to lay the foundation and support an original notion you propose in a research report. A literature review, on the other hand, does not attempt to provide any new information; rather, it seeks to synthesize and summarize the theories and assertions of others.

Literature reviews provide a valuable reference for a particular subject. Literature reviews might provide a starting point or summary for time-constrained research projects. They are helpful papers that keep professionals abreast of the most recent developments in their industry. The breadth and depth of the literature review highlight the author's authority in their subject for academics. Literature reviews also provide a research paper's study with a strong foundation. Most research articles require extensive knowledge of the relevant literature.

4.2 LITERATURE REVIEW

For this research, we have studied several existing research articles. Most of them are collected from journals or conferences. We also investigate the selected paper's importance, effect, and relation to our research interest topic. The finding from the research is described below. We targeted those papers which are related to or near to our research interest

4.2.1 Paper 1

A Modified Meander Line Microstrip Patch Antenna with Enhanced Bandwidth for 2.4 GHz ISM-band Internet of Things (IoT) Applications (2019): In paper [131], Islam et al. show an antenna that operates at 2.4GHz, the application area of their proposed antenna is ISM (Industrial, Scientific, and Medical). The dimension of the antenna is 40×10×1.6 mm3. The antenna design comprises an inverse S-shape meander line connected with a slotted rectangular box. The parasitic element has a significant 12.5% influence on the antenna's bandwidth. The finished antenna has a 79% radiation efficiency at 2.4 GHz with a peak gain of -0.256 dBi (measured) and 1.347 dBi (simulated). The measurement of the power produced and received by the antenna at 2.4 GHz is carried out. The findings are compared with those of a dipole antenna to demonstrate the effectiveness and eligibility in IoT applications. According to the paper's author, the IoT application environment validates the new antenna's small compactness and high fractional bandwidth.

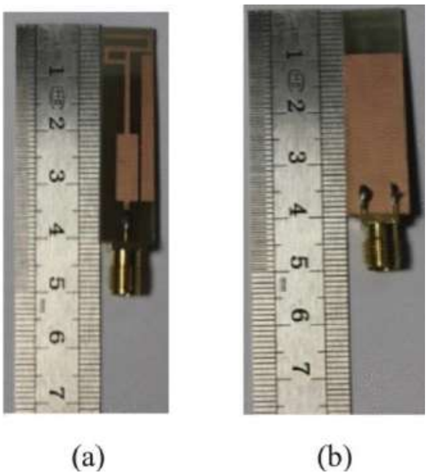


Figure 4.1: Fabricated antenna from ref [131] (a) Front view (b) Rear View.

4.2.2 Paper 2

An Integrated Antenna System for 4G and Millimeter-Wave 5G Future Handheld Devices (2019): In research [132], the author presents a deceptively simple integrated antenna system for mobile devices that operates at millimeter-wave frequencies and uses Defected Ground Structure (DGS). The 110 mm x 75 mm by 0.508 mm thick Rogers RT/Duroid 5880 substrate is used in the simulation of the proposed design. T-shaped 1 2 power divider/combiners activate antenna arrays, which radiate from the structure. Dual bands for 4G are realized, with centers at 3.8 GHz and 5.5 GHz, and a 5-dB impedance bandwidth of 24.4-29.3 GHz is realized with the 5G antenna array. The max gain of the 4G antenna array is 5.41 dBi, and its operating bandwidth is 20 MHz. Gain of 10.29 dBi at the peak is attained using the 5G mm-wave system. Due to the high degree of isolation between the two antenna modules, a single integrated system may function well over two frequency bands. A working prototype of the antenna is constructed, and its performance in the far field is measured to back up the hypothesis. Simulations and experiments provide consistent findings. The beam steering capabilities of the proposed mm-wave 5G antenna array are also assessed using CST®MWS®. The advantages of the shown structure are its compactness, planarity, high gain, and broad bandwidth. The measured radiation properties prove that the suggested design is appropriate for existing and future wireless portable devices.

4.2.3 Paper 3

Reconfigurable metamaterial structure for 5G beam tilting antenna applications (2020): In article [133], Esmail *et al.* present a metamaterial (MTM) structure that operates in the millimeter-wave (mm-wave) spectrum and has a reconfigurable characteristic. The planar dipole antenna of the fifth generation, which has been suggested, works at a frequency of 28 GHz. Because the proposed antenna's electromagnetic (EM) rays go through various MTM configurations whose phases are distinct, the radiation beam is subsequently angled in the direction of an MTM configuration with a high refractive index. The radiation beam of the proposed antenna loaded by MTM is shown to be tilted in the E-plane by angles of either +34° or 31°, depending on which of the two MTM configurations is arranged onto the antenna substrate, according to the results of both simulated and measured versions of the antenna's operation. In addition, the gain is increased by 1.7 dB for positive tilting angles and by 1.5 dB for negative tilting angles, respectively. At 28 GHz, the reflection coefficients of the antenna with MTM are maintained to be less than -10 dB.

4.2.4 Paper 4

A CPW-fed flexible UWB antenna for IoT applications (2018): T.K.Saha and others published a journal [134], where their study offers an inkjet printed ultra-wideband (UWB) flexible antenna on photo paper. The antenna pattern is comprised of a circular patch with a double-stepped symmetric ground plane, and it is fed by a coplanar waveguide (CPW) method that is performed on a one-sided photo paper. The antenna can function at a frequency range of 3.2–30 GHz with a return loss of - 10 dB or less and a voltage standing wave ratio (VSWR) of less than 2. The suggested monopole antenna has physical dimensions of 33.1 millimeters by 32.7 millimeters by 0.254 millimeters, and its electrical size is 0.35 k by 0.35 k when operating at 3.2 gigahertz. This design's radiation pattern is almost wholly omnidirectional throughout the impedance spectrum. It was found that there was an average gain of 4.87 and that the radiation efficiency was 86.61%. Wearable and Internet of Things (IoT) applications are ideal for an antenna made out of paper substrate because of its tiny size, more fantastic operational range, steady radiation pattern, and higher allowable peak gain.

4.2.5 Paper 5

Compact Planar Multi-Standard MIMO Antenna for IoT Applications (2018): In paper [135], the researchers have introduced a unique compact single-substrate planar multiband 5-element multiple input multiple output (MIMO) antenna system. The antenna covers the radio frequency identification (RFID) bands centered on 2.4 GHz and 5.8 GHz, as well as the long-term evolution (LTE) frequency ranges below 1.0 GHz (687 MHz-813 MHz). The additional tiny MIMO antennas with two elements work with frequency ranges ranging from 754 MHz to 971 MHz, 1.65 GHz to 1.83 GHz, 2 GHz to 3.66 GHz, and 5.1 GHz to 5.6 GHz, respectively. The proposed antenna is integrated with a wideband sensing antenna for spectrum sensing in the frequency range of 0.668 GHz-1.94 GHz and 3 GHz-4.6 GHz. The antenna is constructed on a low-cost FR-4 substrate that measures 65 millimeters by 120 millimeters by 1.56 millimeters. Also experimentally validated is that the MIMO antennas' envelope correlation coefficient (ECC), based on the 3D radiation pattern, is less than 0.5. The antenna in a realistic application environment is the step in demonstrating the platform's usefulness for the internet of things (IoT) applications.

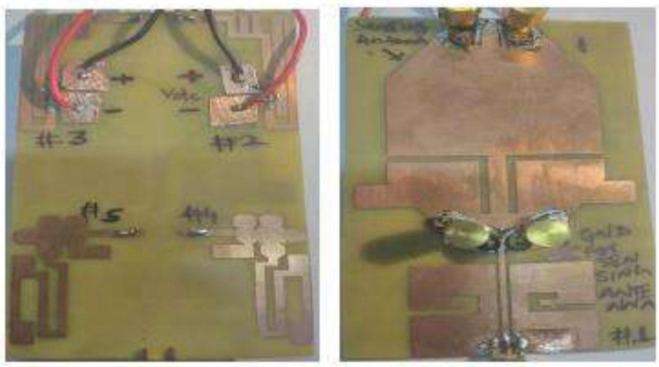


Figure 4.2: Fabricated antennas (a) top and (b) bottom faces of [135].

4.2.6 Paper 6

4-Element MIMO Antenna with CSRR and Meandered Line Loaded for Multiband Applications (2020): In paper [136], M.K.Sharma and others presented a four-port MIMO antenna suitable for use in multi-band applications. The construction of the antenna is made up of radiating components that have been fed in steps. The ground plane loaded with a Complementary Split Ring Resonator (CSRR) and meandering line slots help to create numerous resonances. The suggested antenna exhibits resonant behavior in the hepta-band frequency range. The suggested antenna has a resonant frequency of 3.5 GHz and 6.5 GHz, 10.9 GHz, 18 GHz, 11 GHz, 14 GHz, and 28 GHz. These frequencies are helpful for WLAN, WiMAX, 5G networks, and Radar systems. The antenna is built onto the Roger substrate, which has a total dimension of 36 by 36 millimeters. Over the relevant frequency bands, the antenna has an overall peak gain of 7 dBi on average. The suggested antenna's gain, efficiency, operational bandwidth, and isolation are evaluated and compared to antennas that have already been published in the relevant literature. The

ECC of the suggested MIMO antenna is less than 0.1, and other adequate MIMO performance parameters are to be examined as the proposed antenna is a good contender for various wireless applications.

4.2.7 Paper 7

Small patch and slot microstrip arrays for IoT and ISM band applications (2020): Researchers discuss designing and manufacturing a two-antenna array that resonates at 5.8 GHz in the study [137]. This frequency fulfills several applications, most notably those related to the ISM band, but it also includes applications linked with the internet of things. The array has a measured bandwidth of 617 MHz (from 5.503 to 6.120 GHz, or 10.63% of the central frequency) when it is built on a thin substrate, but it only has a bandwidth of 455 MHz (from 5.517 to 5.972 GHz; 7.84% about the central frequency) when it is fabricated using a thicker substrate. The measured gains were 6.7 dBi and 7.2 dBi, respectively, whereas the simulated gains were 6.89 dBi and 7.63 dBi. The decrease in size is more than thirty percent, and the efficiency of the simulations is more excellent than ninety percent.

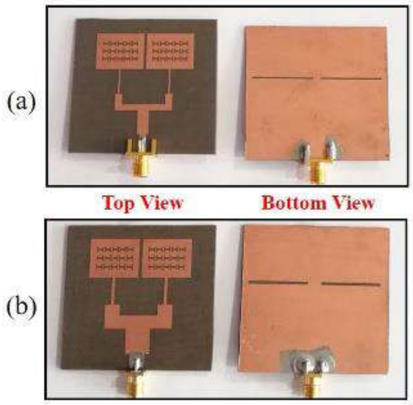


Figure 4.3: Fabricated antenna arrays on DiClad 880 with a thickness (h) of (a) 0.787 mm, and (b) 1.575 mm [137].

4.2.8 Paper 8

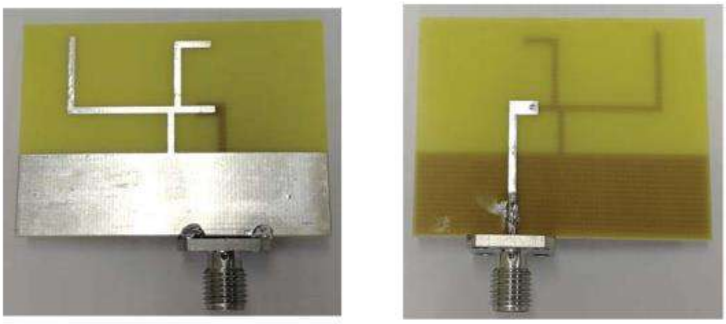
Shared Aperture Slot-Based Sub-6 GHz and mm-Wave IoT Antenna for 5G Applications (2021): A square concentric slot-based antenna for sub-6 GHz and millimeter wave (mm-wave) 5G enabled Internet of Things (IoT) devices is discussed in a research article [138]. A standard radiating aperture for both sub-6 GHz and mm-wave bands is one of the distinctive characteristics of the design that is being suggested here. The antenna comprises three-square slots carved in a concentric pattern from a ground plane with dimensions of 50 by 50 millimeters squared. When operating in the sub-6 GHz range, the antenna is stimulated by a single open-ended microstrip transmission line. However, when operating in the mm-wave spectrum, a 1:8 power divider (PD) is utilized to excite the planar-linked antenna arrays. The suggested antenna is capable of operating in the sub-6 GHz range and covers the following eight frequency bands: 1.05-1.23 GHz, 1.4-1.55 GHz, 1.9-2.3 GHz, 2.3-2.7 GHz, 3.1-3.7 GHz, 4.04-4.511 GHz, 4.83-5.2 GHz, and 5.66-6.151 GHz. The mm-wave band has a minimum bandwidth (BW) of 1 GHz and operates between 27.4 and 28.4 GHz. Since the suggested antenna covers the majority of IoT bands, it is a strong contender for inclusion in the next generation of 5G-enabled Internet of Things devices.

4.2.9 Paper 9

A Single-Fed Multiband Antenna for WLAN and 5G Applications (2020): Article [139] proposes a multiband slotted conical patch for microwave and millimeter-wave applications. The antenna is attached to a tiny triangular patch and has slots. The antenna that was developed has these three features. At its lowest operating frequency, which is 2.4 GHz, the multiband antenna that has been presented has a tiny size of 0.35 0.35 0.004, and, more crucially, it can cover both the microwave and millimeter-wave bands with a single feeding. The experimental findings indicate that the antenna functions at (2.450–2.495) GHz, (5.0–6.3) GHz, and (23–28) GHz, according to the matching bandwidth of 10 dB. Some of the benefits of this design over the systems described in the most recent literature include the smaller size, simpler architecture, and larger multi-band bandwidth. The suggested antenna may be used for wireless local area network (WLAN) applications and fifth-generation (5G) wireless communication devices.

4.2.10 Paper 10

Design of Low-profile Dual-band Antenna for IoT Applications (2019): In paper [140], the researcher has presented a low-profile dual-band antenna whose operating frequency is 1.8 and 2.4 GHz, respectively. The proposed antenna is fabricated on a fragile substrate with a thickness of 0.6 mm. The two radiating microstrip branches of PIFA are of different lengths to achieve dual-band operation. The proposed antenna has the benefit of simple structure, low cost, and easy manufacturing, and the antenna is suitable for wireless applications.



(a) Top view (b) Bottom view

Figure 4.4: Fabricated proposed antenna of [140].

4.2.11 Paper 11

Compact Slot Antenna Array for 5G Communications (2019): A tiny multiband antennas encompassing the FR1 and FR2 new radio frequencies utilized by 5G provide a significant challenge to researchers in the area of wireless communication. In this research study [141], the researcher have described a dual-band antenna measuring 18 x 16 x 0.285 mm3 that operates between FR1 and 5.8 GHz, as well as a triple-band antenna measuring 30 x 25 x 0.543 mm3 that operates between FR1-3.5 GHz, 5.8 GHz (sub-6 GHz microwave frequency bands), and FR2-28 GHz (mm-wave frequency band). The compact, finalized design for the three-band antenna has impedance bandwidths of 12.71 percent at 3.5 GHz, 11.32 percent at 5.8 GHz, and 18.3 percent at 28 GHz, with gains of 1.86 dB, 2.55 dB, and 4.41 dB, respectively. The measured radiation parameters of the prototypes confirm the feasibility of the proposed designs for futuristic 5G-RFID and mobile Internet of Things (IoT) applications.

4.2.12 Paper 12

Compact dual and triple band antennas for 5G- IoT applications (2021): Researchers in paper [142] have designed tiny multiband antennas capable of concurrently covering both new radio frequencies by 5G (FR1 and FR2). A dual-band printed antenna with dimensions of 18 by 16 by 0.285 mm 3 that operates at FR1–5.8 GHz and FR2–28 GHz and a triple-band printed antenna with dimensions of 30 by 25 by 0.543 mm 3 that operates at FR1–3.5 GHz and 5.8 GHz (sub-6 GHz micro-wave frequency bands) and FR2–28 GHz are both presented in this paper. The dual-band printed antenna has a size of 18 (mm-wave frequency band). The final, planned tri-band antenna has a small dimension and an impedance bandwidth of 12.71%, 11.32%, and 18.3% at 3.5 GHz, 5.8 GHz, and 28 GHz, with the gain equivalent to 1.86 dB, 2.55 dB, and 4.41 dB, respectively. As a result of the radiation characteristics that were tested on the manufactured prototypes, it was determined that the suggested designs are appropriate for cutting-edge 5G-RFID and mobile Internet of things (IoT) applications.

4.2.13 Paper 13

Common-Aperture Sub-6 GHz and Millimeter-Wave 5G Antenna System (2020): In paper [143], an integrated design of the antenna is proposed that functions at several bands, such as sub-6 GHz at 3.6 GHz and mm-wave at 28 GHz, has been proven as a combination of a dipole and tapered slots. Designing an antenna begins with a dipole that operates at 3.6 GHz and is fed by a modified balun consisting of a tapered slot and a microstrip wire. The dipole supplies this balun. In this case, the tapered slot serves a dual purpose; at 3.6 GHz, it is used to excite the dipole, and at 28 GHz, it performs the function of an antenna for tapered slots. The fact that just one feeder is optimized and utilized for both structures contributes to the one-of-a-kind design of the system, which also offers an exceptionally high-frequency ratio. In addition, the dipole arms serve as an antenna footprint for two tapered slot mm-wave arrays, turning the dipole into a device with dual capabilities. The primary beams of the tapered slot antenna and the mm-wave arrays are adjusted to point in various directions to maximize their performance. The design can cover an arc of space of 120 degrees in the direction of this layout. A prototype with an overall dimension of 75 mm3 x 25 mm3 x 0.254 mm3 is manufactured on Rogers RO-5880 as a proof of concept. The viability of the suggested approach has been shown, both via simulation and measurement.

4.2.14 Paper 14

Shared-Surface Dual-Band Antenna for 5G Application (2019): Paper [144] suggests a shared-surface dual-band antenna for 5G operation (CMA) with characteristic mode analysis. At the Ka-band frequency, the surface is an integration of a metasurface at the lower S-band and a partially reflecting surface (PRS) at the higher Ka-band frequency. A microstrip-fed slot is used to excite the resonant mode of the metasurface, and a pair of substrate integrated waveguide (SIW)-fed slots are used in conjunction with a PRS to create a Fabry-Perot resonator antenna (FPRA). A physical prototype of the antenna was used to conduct measurements, which revealed that the antenna has a 10-dB impedance bandwidth of 23.45% and 9.76%, as well as a realized gain that ranges from 7.27 to 10.44 dBi and from 11.8 to 14.6 dBi, respectively, over the S-band (3.2-4.05 GHz) and the Ka-band (26.8-29.55 GHz).

4.2.15 Paper 15

Substrate-Integrated Two-Port Dual-Frequency Antenna (2016): The researchers of [145] show a substrate-integrated antenna with a two-port dual-frequency configuration with a significant frequency gap between the two frequencies. These two antennas are responsible for low and high-frequency emissions, respectively. The former is loaded by a hollow patch, while the latter is manufactured within the hollow area of the patch by using air holes and metalized vias. Both of these methods are described in the following sentence. A second substrate lies underneath the antenna substrate, and it is on this second substrate that the slot-coupled sources that feed the two antennas are printed. To demonstrate its functionality, a two-port dual-frequency antenna that operates in the WLAN band at 5.2 GHz and the ISM band at 24 GHz was developed, constructed, and measured. It is stated that the two antenna sections each have their unique S-parameters, radiation patterns, and antenna gains. The measured findings and the simulated outcomes seem to accord with one another to a reasonable degree. Here extreme isolation of over 35 dB can be seen between the two different components of the antenna.

4.2.16 Paper 16

An Aperture-Sharing Array for 3.5/28 GHz Terminals with Steerable Beam in Millimeter Wave Band (2019): In the study [146], an aperture-sharing approach is devised so that a four-unit linear 28 GHz array and a 3.5 GHz dipole antenna are presented where they integrated and shared the same aperture. The substrate integrated waveguide, abbreviated as SIW, is used to make the integration possibilities and to keep the radiation of both antennas from interfering. Each mmWave array unit is activated thanks to a separate feeding network, making it possible for the mmWave band to produce a steerable beam in the E-plane. Using a standard aperture allows for fabricating a prototype with more condensed dimensions. The results of the measurements demonstrate that the radiation properties are satisfactory and that the 10 dB impedance bandwidth exceeds 20% in both bands. In addition, the mmWave beam steering may be accomplished with a consistent degree of gain. The dual-frequency antenna that has been designed is well suited for several terminal applications in the future generation of wireless technology.

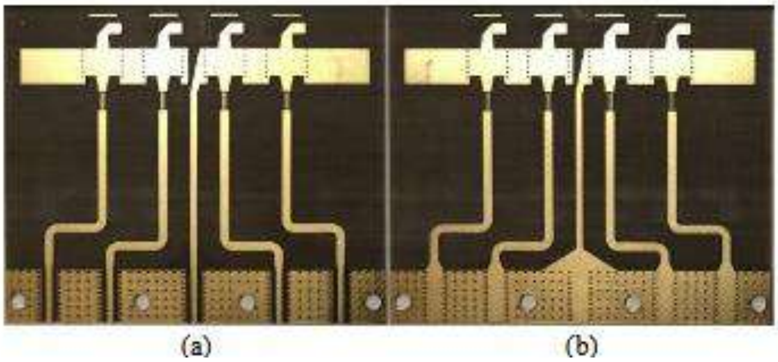


Figure 4.5: Photographs of the proposed antenna. of [146] (a) Top view. (b) Bottom view.

4.2.17 Paper 17

A Tri-band Shared-Aperture Antenna for 2.4/5.2-GHz Wi-Fi Application with MIMO Function and 60-GHz Wi-Gig Application with Beam-Scanning Function (2020): The design and implementation of a tri-band shared-aperture antenna that can operate at frequencies of 2.4, 5.2, and 60 GHz are presented in the study [147]. It then implements the Wi-Fi application with the multiple-input multiple-output (MIMO) function and the Wi-Gig application with the beam-scanning function concurrently by placing these three bands of antennas inside the same radiating aperture. Within these two bands, the observed radiation efficiencies range from 74% to 95% and 76% to 95%, respectively. In addition, the Wi-Gig antenna can achieve both a high gain and a broad range of beam coverage concurrently since the whole design arrangement has been carefully considered and optimized. The highest gain was measured to be 12.29 dBi, while the beam coverage was found to be 36° between 57 and 64 GHz. The envelope correlation coefficients (ECC) estimated from the simulated and observed data all had values less than 0.04.

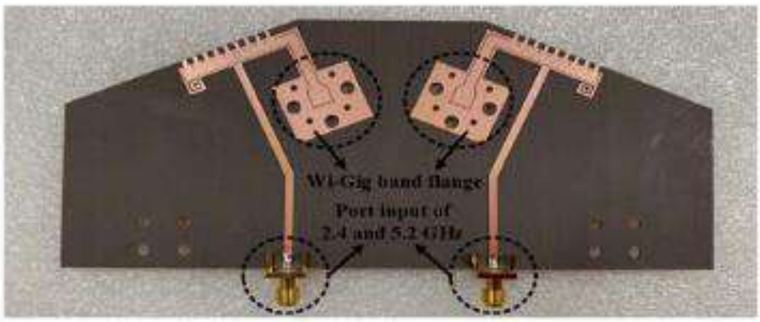
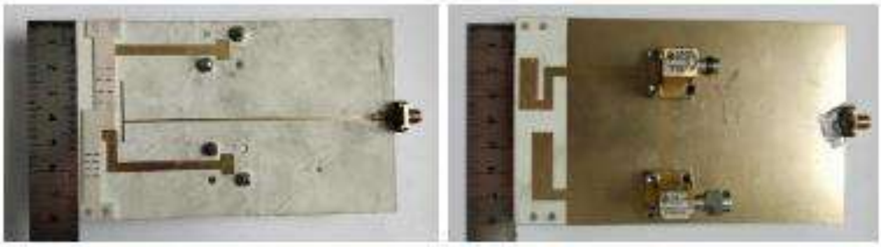


Figure 4.6: Prototype of the fabricated triband shared-aperture antenna [147].

4.2.18 Paper 18

A Compact Hepta-Band Mode-Composite Antenna for Sub 6 GHz, 28 GHz and 38 GHz Applications (2020): A co-designed hepta-band antenna with a high-frequency ratio is presented in the paper [148]. At microwave frequencies, the properties of the radiation are kept stable. The idea behind this method is that in addition to a quasi-TE 10 mode transmitting in a substrate integrated waveguide (SIW) structure at millimeter-wave frequencies, additional radiation modes of the wire antennas can be excited simultaneously on the outer surface of a well-designed SIW structure at microwave frequencies that are much lower than the cut-off frequency of the SIW. The mode-composite structure of this design is constructed using a combination of a meander SIW section and an L-shaped SIW section coupled with a metallic ground plane. With the help of parasitic dipole components located near the slots, it is possible to create unidirectional features with low backward radiation levels. Exciting the five radiation modes present on the outer surface of the mode-composite structure requires a T-shaped probe that functions as a coupled feed which allows the structure to cover five sub-6-GHz bands, which are necessary for LTE and 5G mobile communications as well as WLAN applications.



(a) (b)

Figure 4.7: Photographs of fabricated hepta-band antenna prototype of [148]. (a) Top view. (b) Rear view.

4.2.19 Paper 19

Dual-Frequency Folded-Parallel-Plate Antenna With Large Frequency Ratio (2016): In paper [149], a novel small dual-frequency antenna with a significant frequency ratio comprising a pair of folded parallel plates is presented. The antenna can operate at two different frequencies simultaneously. It blends the millimeter-wave Fabry-Perot resonator antenna (FPRA) with the microwave parallel-plate waveguide resonator antenna (WRA), with their resonance frequencies independent of one another. The typical parallel-plate WRA has a higher profile than the suggested folded structure, which results in the proposed antenna having a lower profile. The WRA component is stimulated by a hook-shaped strip on its top, while an L-shaped probe stimulates the FPRA component with a half-ring sleeve. A dual-frequency antenna that operates in both the 2.4- and 24-GHz ISM bands was developed to provide concrete evidence of the concept's validity. The S-parameters, radiation pattern, and antenna gain were simulated using ANSYS HFSS, and there is a fair agreement between the simulated results and the measured ones.

4.2.20 Paper 20

Multiband MIMO Microwave and Millimeter Antenna System Employing Dual-function Tapered Slot Structure (2019): In paper [150], the researcher has developed an antenna For use in future wireless devices capable of functioning in the WLAN (2.45 GHz), 4G LTE (2.6 GHz), and 5G (24, 28 GHz) bands, a single-layered multiple-input multiple-output (MIMO) antenna system. The configuration utilizes a dual-band 4-element monopole MIMO antenna system that operates across the 2.45 GHz and 5.2 GHz frequency bands. A decoupling mechanism is developed based on a tapered slot built into the ground plane. This tapered slot serves as a decoupling structure (0/4 of a wavelength long) at 2.45 GHz and a tapered slot antenna (30 of a wavelength long) at 28 GHz when the appropriate feeder drives it. This slot has a dual purpose. On top of an RO-5880 substrate with overall dimensions of 104 by 104 by 0.51 mm3, the MIMO antenna system that has been suggested has been developed. Based on the results of the measurements, it has been determined that the design in question is capable of covering one high-frequency band (23-30 GHz) with a peak gain of 11 dBi and two low-frequency bands (2.40-2.80, 5.1-5.6 GHz) with a peak gain of 5 dBi. While the highest measured value of the envelope correlation coefficient is more than 0.16, the lowest measured isolation between the two antennas is greater than 16 dB, indicating that the MIMO properties are satisfactory.

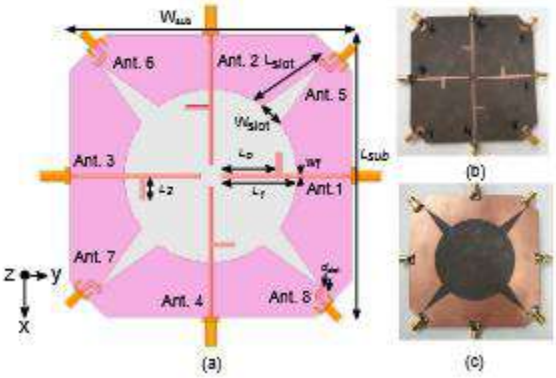


Figure 4.8: (a) Geometry of the proposed MIMO antenna system and photograph of the fabricated prototype of [150] (b) top view, and (c) bottom view.

4.2.21 Paper 21

A Dual-Element MIMO Antenna System with a mm-Wave Antenna Array (2016): In the research article [151], the author has shown an integrated antenna system for both now operational 4G and soon-to-be operational 5G broadband communication systems. The integrated solution combines a millimeter (mm)-wave antenna array and a microwave multiple-input-multiple-output (MIMO) antenna system. While the MIMO antennas run across a wide band spanning numerous well-known wireless standards between 1870 and 2530 MHz, the mm-wave antenna array operates at 28 GHz with a minimum bandwidth of 1.7 GHz. Both of these frequencies fall within the range of the electromagnetic spectrum. The construction of the suggested design is straightforward, and it uses antenna parts with a low profile. The integrated antenna system is constructed on a printed circuit board with many layers that are the size and shape of a conventional Smartphone handset. The board has dimensions of 60 by 100 by 0.965 millimeters in volume. The design presented is appropriate for use in tiny wireless portable devices and mobile terminals conforming to 4G and 5G standards.

Figure 4.9: Fabricated model of [151] (a) Top view (b) Bottom view.

4.2.22 Paper 22

A Photovoltaic Cell Integrated Slot Antenna for IoT Applications (2020): For use in Internet of Things (IoT) applications, a photovoltaic cell integrated slot antenna is proposed in research [152]. The antenna is small and has a low profile. A top metal grid, a layer of GaAs, and a bottom metal contact are the three components that make up the photovoltaic cell. The bottom metal contact of the photovoltaic cell is given a slot through which a slot is etched; thus, the bottom metal contact is used as a ground plane for the antenna. A microstrip line with a 50- impedance is used to excite the slot on the ground plane. The antenna dimensions are 25 millimeters by 25 millimeters by 0.885 millimeters

(0.48 degrees by 0.48 degrees by 0.017 degrees at 5.77 gigahertz). The antenna's performance demonstrated an impedance bandwidth of –10 dB from 5.60–5.94 GHz, a peak gain of 3.76 dBi, and radiation efficiency of more than 88% within the impedance bandwidth. The redesigned antenna has the potential to save up a significant amount of space in the Internet of Things devices.

4.2.23 Paper 23

Numerical Design of Quad-Band Antenna for UWB RF Signal Energy Harvesting on IoT Application (2019): An antenna rectifier that will function in the frequency range of 3-10 GHz, a proposal for a quad-band antenna is presented in research [153]. The design of the antenna was based on a model of a double-crossed bowtie that was printed on an FR-4 substrate. Simulation and optimization are carried out to get desirable parameters for both bandwidth and gain. According to the simulation's findings, the antenna can perform well at frequencies of 5.984 GHz, 7.414 GHz, 9.108 GHz, and 10.208 GHz. With a bandwidth of 727.7 MHz and a gain of 3.654 dB, respectively, this antenna has the excellent possible performance in these two categories.

4.2 .24 Paper 24

Compact Broadband Four-Port MIMO Antenna for 5G and IoT Applications (2019): Research [154] introduces a brand-new tiny multiple-input multi-output (MIMO) antenna that has the potential to be used in fifth-generation (5G) networks and the internet of things (IoT). Four coaxial cables power it. Each antenna is constructed using a unique set of inverted L-monopoles and grounded stubs. Different L- monopoles generate different resonant frequencies. The proposed MIMO antenna has a size of 56 millimeters by 56 millimeters by 35.3 millimeters and operates at a frequency range of 2 to 6 gigahertz. It covers the 5G sub-6-gigahertz network communication channel in addition to other multiple communication bands, such as LTE (2.2–3.8 GHz), Bluetooth (2.4 GHz), WLAN (2.4 and 5.1–5.8 GHz), WiMAX (2.3–5.7 GHz), and ISM bands (The envelope correlation coefficient (ECC) is less than 0.04 over the whole operational spectrum when the isolation between each antenna element pair is more than 15 dB. In addition, it has been determined that the realized gain is more than 1.5 dBi and that the radiation efficiency is greater than 85%.

4.2 .25 Paper 25

ACS fed Open-ended low profile antenna for IoT Applications (2021): An asymmetric co-planar strip (ACS) fed open-ended low profile antenna is shown in paper [155] research work. This antenna is ideal for wireless and Internet of Things (IoT) applications. The open-ended antenna design includes a strip of an L linked to the feed line and an L-shape extended with a 7-shape radiating element. The shape of the planned antenna elicited a frequency of operation between 3.45 and 5.8 gigahertz. The suggested antenna is constructed on a low-profile substrate made of FR4, and its total dimensions are 28.5 millimeters by 23 millimeters. The antenna has a gain of 2.7 dBi and radiation efficiency of 97%. Both of these figures are pretty impressive. When the antenna's operating frequency range and other properties are considered, the open-ended low-profile antenna created may be installed into any portable wireless device suitable for 4GHz Internet of Things applications.

4.2.26 Paper 26

Single-fed 4G/5G multiband 2.4/5.5/28 GHz antenna (2018): The study [156] provides a single-fed printed multiband antenna for 4G and 5G wireless communication systems. A Franklin strip monopole antenna for 4G, wireless applications (WLAN and WiMAX), and a rectangular patch antenna for the 5G spectrum make up the multiband antenna that has been proposed. Between the antenna parts, a bespoke small microstrip resonant cell low-pass filter is manufactured in order to feed the Franklin antenna in low-frequency bands while isolating it from the rectangle patch in the 5G spectrum. The suggested antenna has a small dimension of 45 x 40 x 0.508 mm3 and is built on the Rogers 5880 platform. With a large impedance bandwidth of 15.8, 23.5, and 11.3% with gain reaches of 1.95, 3.76, and 7.35 dBi, the suggested antenna is used to function at the triple band frequencies of 2.4, 5.5, and 28 GHz.

4.2.27 Paper 27

Electronically Pattern Reconfigurable Antenna for IoT Applications (2021): In [157], an electrically reconfigurable pattern antenna for Internet of Things (IoT) applications is presented in this paper. The antenna comprises four wire patches that share a common ground plane. This radiating element achieves a 290 MHz frequency bandwidth from 2.25 to 2.54 GHz and can flip between four end-fire radiation states in less than 5 µs. The findings demonstrate that this antenna can achieve a front-to-back ratio of more than 6.5 dB and a peak gain of 3.9 dBi at 2.44 GHz. The radiation pattern steering is accomplished using a solitary low-power, low insertion loss SP4T switch. This method accommodates the IoT microcontroller's restricted resource limits by avoiding the need for many electronic components in the reconfiguration operation. The antenna structure is small and produced on two FR-4 printed circuit boards, which are inexpensive (PCBs). The suggested structure's high performance, small size, low cost, and low-power properties make it appropriate for IoT applications.

4.2.28 Paper 28

2x2 Circularly Polarized Antenna Array with Equal Phases for RF Energy Harvesting in IoT System (2019): The 2x2 planar circularly polarized (CP) antenna array is demonstrated in [158] for RF energy harvesting in IoT system applications. The single element is a coplanar waveguide (CPW) feed line-equipped slot antenna. A grounded-L strip, a stepped impedance matching stub, two chamfered corners, an asymmetric U-shaped strip serving as a perturbed element, and a center slot radiator make up this radiator. A voltage doubler rectifier is constructed along with the slot antenna to complete a rectenna structure. Then the CPW feed antenna element is used to design the 2x2 planar antenna array. The array elements are all pointed in the same direction and are supplied by a corporate feeding network with equal-phase feeding behavior. The CPW feed antenna components are connected to the microstrip Wilkinson power divider via holes. A proposed array prototype is created and measured. Between observed and computed reflection coefficients, there is a good agreement. There is noticeable front and back radiation, and two primary lobes at 0o and 180o are shown. For AR 3 dB, the array axial ratio bandwidth (ARBW) is equivalent to 180 MHz. At 2.45 GHz, the array has a gain of 6.605 dBi, a directivity of 9.604 dBi, and a radiation efficiency of 50.12%. The suggested array receives RF power of about -9.37 dBm lower than the single element collected power at 2.445 GHz.

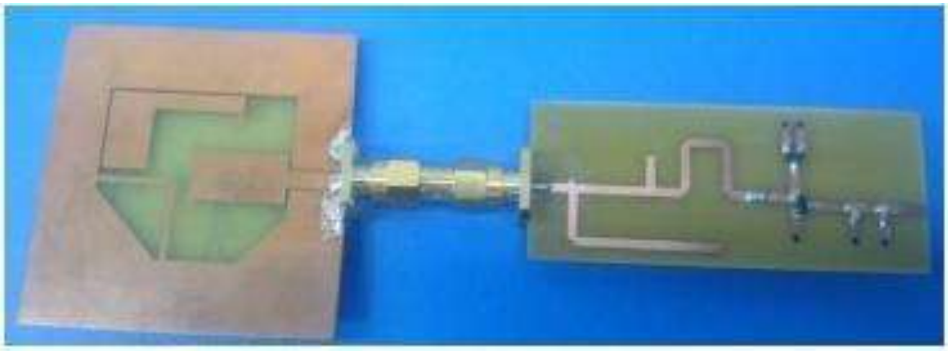


Figure 4.10: Photograph of the fabricated antenna of [158].

4.2.29 Paper 29

High-Gain Wideband Parasitic Microstrip Antenna for 5G and IoT at 26 GHz (2021): A high-gain wideband parasitic microstrip antenna for 26 GHz 5G and IoT applications is presented in this study [159]. First, a single antenna targeting the 5G New Radio (NR) Frequency Range 2 (FR2) band n258 and made up of a miniature parasitic patch antenna has been investigated, described, and optimized to function at 26 GHz. The suggested antenna surrounds a core patch fed by a probe with eight parasitic microstrip patches arranged in a square pattern. The magnetic and electric field produced by the central active patch connects the patches acting as parasite elements. Simulations show that a single optimized array antenna, following optimization in CST MWS, has a total dimension of 24x24 mm^2, which corresponds to 2.12.1 of the operating frequency, an effective gain of 14.4 dBi, and a total bandwidth of 4.15 GHz (16.29%).

4.2.30 Paper 30

Compact Dual-Band Printed Monopole for 5G/IoT(2020): This [160] study suggests a dual-band antenna that operates in the Ka-band in light of the expanding need to communicate with various RF frontends and the tendency of millimeter waves to migrate because of the wider bandwidth available. The dual-band monopole-based structure ensures high efficiency for both 28 and 38 GHz, which isolates each frequency through the feeding network. Additionally, measured bandwidths of 15% or so for each frequency were attained.

4.2.31 Paper 31

Metamaterial-based Antipodal Vivaldi Wearable UWB Antenna for IoT and 5G Applications (2020): The antipodal Vivaldi metamaterial-based flexible wearable ultra-wideband (UWB) antenna presented in this [161] research operates at 4.25–35 GHz for sub-6G, IoT, and wireless body area network (WBAN) applications. The suggested tiny antenna (15x10 mm^2) consists of a ShieldIt resonator and a layer of denim with a thickness of 0.7 mm. To be a viable candidate for sub-6G communications, a modified leaf-shaped antipodal patch has been created with a broad bandwidth, high directional gain, and high efficiency. First, to increase the antenna's radiation efficiency while suppressing unwanted surface waves, the patches are cut by two half-circle arcs, two stubs at the front, and two L-shape slots at the back. Then, using a semi-flexible Rogers 5880 substrate (h = 0.508 mm), the antenna is loaded with the suggested metamaterial arrays to increase its gain and directivity while extending its bandwidth (BW). Additionally, the antenna's components have all been carefully designed and tuned to achieve maximum directed gain and radiation efficiency of 8.97 dBi and 98%, respectively. The high agreement between modeling and measurement findings demonstrates the antenna's suitability for sub-6G, IoT, and WBAN applications.

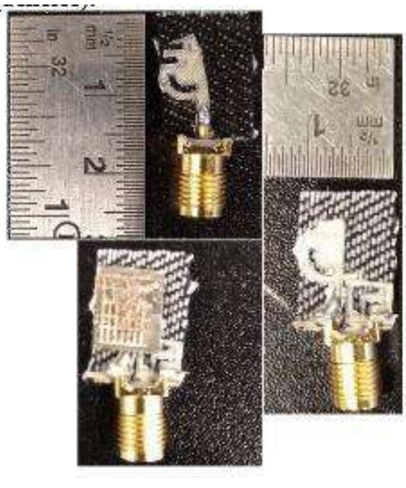


Figure 4.11: The fabricated prototype of the antenna [161].

4.2.32 Paper 32

A Modified Meander Line Microstrip Patch Antenna with Enhanced Bandwidth for 2.4 GHz ISM-band Internet of Things (IoT) Applications (2019): The study [162] proposes a modified meander-shaped microstrip patch antenna for 2.4 GHz ISM

(Industrial, Scientific, and Medical) applications. The antenna measures 40 by 10 by 1.6 millimeters. The antenna consists of a slotted rectangular box connected to an inverse S-shaped meander line. The design incorporates a parasitic patch with a shaped ground and a capacitive load (C-load). According to investigations, the inverse S-shaped patch and rectangular box microstrip line antenna has greater efficiency and gain than the typical meander-shaped antenna. To match the impedance, the C-load is applied to the feed line. Additionally, parametric tests are done to look at the antenna's flexibility. According to the results, the rectangular box can be modified to increase gain and efficiency by adding parasitic elements and redesigning the ground. The parasitic element's 12.5% influence on the antenna's bandwidth is significant. The finished antenna has a 2.4 GHz radiation efficiency of 79% and a measured peak gain of -0.256 dBi and 1.347 dBi, respectively.

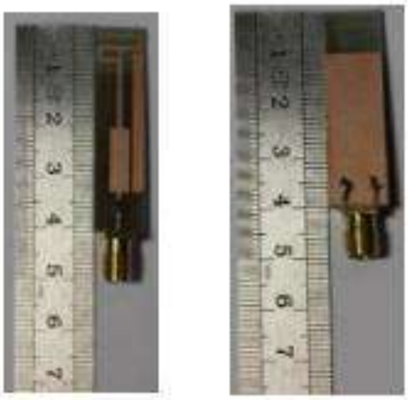


Figure 4.12: Fabricated Antenna of [162] (a) Patch (b) Ground.

4.2.33 Paper 33

Single-Layer, Unidirectional, Broadside-Radiating Planar Quadrupole Antenna for 5G IoT Applications (2021): The proposed antenna in the literature [163], an innovative quadrupole-based broadside-radiating unidirectional antenna, is designed at 28.475 GHz for 5G IoT applications. The planar antenna is based on single-layer technology to enable conformal applications and is produced on a flexible substrate. It comprises two quadrupolar near-field resonant parasitics (NFRP) elements and a coax-fed driven dipole. The unidirectional pattern produced by the broadside-radiating device has a front-to-back ratio of 9.4 dB and a realized gain of 4.85 dBi. The antenna's overall efficiency is 85%. A differential-fed prototype was developed, built, and tested to facilitate the measurements at 1.579 GHz. The results from simulation and measurement are well-aligned.

4.2.34 Paper 34

Low-Cost and Highly Flexible Antenna for 2.4 GHz IoT applications (2019): To illustrate the viability of Silicone Sponge Rubber (SSR) as a flexible RF substrate, a low-cost and highly flexible patch antenna has been developed in [164]. The material permits the manufacturing of conformal antennas that are exceedingly flexible. When a conformal surface antenna is needed, the Internet of Things (IoT) is the intended use of the antenna. Simulation and measurement results for many conformal surfaces are provided.

4.2.35 Paper 35

Penta-band Dual-fed Smart Glasses IoT Antenna (2020): This [165] paper introduces the method of designing the multiband dual-fed dipole antenna for smart glasses. Two ports with an inductive coupler element (ICE) and capacitive coupler element (CCE), respectively, are assigned in the middle of the dipole by making use of the glasses frame and the theory of typical mode (TCM). Therefore, theoretically, this wire antenna's characteristic modes may be excited. The antenna then covers four ISM bands for Internet of Things applications, including 433 MHz, 915 MHz, 2450 MHz, and 5800 MHz, via impedance matching to the two ports (IoT). It also includes the GPS L1 band considering the positioning function (1575 MHz).

4.2.36 Paper 36

Compact Dual-Band Antenna With Broadside and Conical Radiation Patterns for NB-IoT Applications (2020): This [166] work proposes a small single-fed dual-band dual-mode antenna with different polarization and emission patterns. According to simulation results, the proposed antenna is a strong option for machine-to-machine (M2M) communication systems for narrowband Internet of things (NB-IoT) applications. The even and odd coupled modes of a differential shorted patch antenna (DSPA) can be activated in the original design by cutting out one of the feeds. The suggested antenna exhibits two operational bands with horizontal broadside polarization and conical vertical polarization, respectively.

4.2.37 Paper 37

Low Cost Flexible Antenna for IoT Applications (2020): In [167], a small, flexible, conformal antenna for multiband applications is proposed. IoT, Wi-Fi, Bluetooth, and ISM band are just a few of the uses for the antenna. The antenna covers the 0.773-0.883 GHz, 2.1-2.7 GHz, and 5.2-6.4 GHz frequency bands with a -6 dB impedance bandwidth. Since the antenna is made of a flexible acrylic sheet, conformal applications are appropriate. Also put forth is a plan to incorporate the antenna into the Internet of Things hardware.

4.2.38 Paper 38

A Single Port Orthogonally Polarized Antenna for Handsets, IoT Terminals and Vehicles (2020): This paper [168] designed a broadband resonant antenna for mobile devices, automobiles, and the Internet of Things terminals. It doesn't use expanded ground planes, matching, or tuning circuits. It may be folded or curved to fit around the terminal's slender sides, enabling practical MIMO arrangements with solid isolation. It can effectively receive signals with varying polarization from various directions in any complex environment. Developing a single-port orthogonally polarized terminal antenna has diminished the requirement for spatial diversity MIMO. It offers good sensitivity to circular polarization, which is necessary for GPS and satellite phones and is equally sensitive to two perpendicular polarizations. A single port orthogonally polarized antenna can thus replace any two orthogonally polarized MIMO antennas. In some applications, such as cars, a linearly polarized antenna, and a single-port orthogonally polarized antenna can be combined to create a functional MIMO configuration.

4.2.39 Paper 39

On the Way to Green IoT Antennas: Compact Ultrathin CPW-Fed Monopole on Tencel (2020): A small, incredibly thin, and environmentally friendly antenna for IoT applications around 2.45GHz is presented in this [169] study. Tencel, a fabric made from plants, is investigated for application. Its appropriateness is assessed by contrasting the performance of the novel antenna with Tencel and a traditional RO3003 dielectric with an equal relative dielectric permittivity. To evaluate the value of this contribution, not only in terms of decreasing the ecological footprint and skin comfort but also in terms of size reduction and radiation efficiency, a comparison with a newly published wearable antenna appropriate for IoT in the same band is presented.

4.2.40 Paper 40

A U-shaped wide-slot dual-band broadband NB-IoT antenna with a rectangular tuning stub (2020): To address the needs of NB-IoT dual-band and broadband communication, a wide-slot U-shaped dual-band antenna is proposed in [170]. The dual-band properties of the proposed antenna are formed by its broad rectangular tuning stub, which excites two distinct operating modes. On the antenna's ground plate, a large slot in the shape of a U is employed to provide electromagnetic coupling and enable the antenna's broadband properties. It achieves the dual-band broadband features of the NB-IoT antenna, widens the WLAN and Bluetooth bands, and covers the NB-IoT communication band. The impedance bandwidth (RL-10dB) of the antenna is 0.80-2.88 GHz (relative bandwidth is 97.7%) and 3.96-6.35 GHz (relative bandwidth is 43.5%), according to the simulation findings.

(a) top view (b) back view

Figure 4.13: Photograph of the fabricated antenna [170] (a) top and (b) bottom Views.

4.2.41 Paper 41

Low-Profile ESPAR Antenna for RSS-Based DoA Estimation in IoT Applications (2019): In this publication [171], researchers provide a low-profile electrically steerable parasitic array radiator (ESPAR) antenna that may successfully be utilized to predict the direction-of-arrival (DoA) of incoming signals in wireless sensor network (WSN) applications where the total antenna height must be kept low. The suggested antenna may provide eight distinct primary beam directions, has a cost almost three times lower than high-profile ESPAR antenna designs currently available in the literature for DoA estimation, and depends on streamlined beam steering, making it suited to basic and low-cost WSN nodes. Our fabricated ESPAR antenna prototype was used for testing. The results show that accurate DoA estimation results can be obtained with error levels comparable to those of high-profile ESPAR antennas using the same energy-efficient simplified beam steering concept and having 12 distinct main beam directions. As a result, utilizing the suggested antenna, the entire time needed for DoA estimation can be cut by 33%.

4.2.42 Paper 42

Compact Multiport MIMO Antenna System for 5G IoT and Cellular Handheld Applications (2021): This [172] study introduces a low-profile, small, four-element, eight-port, MIMO and diversity antenna for 5G Internet of Things (IoT) and portable cellular applications. Four components in this antenna arrangement share the same configuration. The antenna ground measures 60 mm by 120 mm, which is equivalent to the size of a contemporary mobile phone. The four antenna elements are at the four corners of the antenna ground structure. Two feeding ports are present on each antenna element, resulting in an eight-port antenna overall. Using two feeding plates positioned perpendicular to one another, a single antenna element can utilize polarization variety by becoming cross-polarized. In contrast, different antenna elements also have spatial diversity. Slots have been etched along the ground plane's length, and rectangular slots have been carved out of the ground plane beneath each antenna element to lessen mutual interaction between various antenna ports. Most of the frequency bands designated for the 5G sub-6 GHz spectrum are covered by the minimum bandwidth of more than 1.4 GHz, obtained by all eight ports for S11 -10 dB, and ranges from 2.4 GHz to more than 3.8 GHz. The minimum value of the isolation between separate ports is -13 dB, and the maximum value is lower than -30 dB. The measured peak gain ranges from 3.2 to 5 dB for the frequency bands covered by this antenna configuration, while the correlation coefficient is below 0.03 in the bands of interest.

4.2.43 Paper 43

A Multiband Multibeam Antenna for Sub-6 GHz and mm-Wave 5G Applications(2022): The concept of a dual-band antenna with a very high-frequency ratio is presented in this study [173], which may be appropriate for combined 4G/mm-wave fifth-generation (5G) and beyond 5G applications for IoT devices. The antenna is built around a tapered slot, which functions as a high-gain Vivaldi antenna at high frequency and a resonant open-ended slot at low frequency. The impedance bandwidth is increased by altering the slot form or adding many sections to the slot. Based on this methodology, a multi-beam antenna covering numerous bands at lower frequencies ranging from 2.5 to 6 GHz is designed at an mm-wave frequency (gain of 10 dBi). The design is mathematically and empirically confirmed regarding return loss, radiation efficiency, gain, total scan pattern, and coverage efficiency.

4.2.44 Paper 44

A 28- and 60-GHz Dual-Band On-Chip Antenna for 5G-Compatible IoT-Served Sensors in Standard CMOS Process (2021): For newly emerging 5G-compatible IoT-served sensor nodes, a dual-band on-chip meander-line monopole antenna is suggested and shown in this study [174]. To protect the antenna from its deployed environment and improve its radiation efficiency and gain over the two bands of interest, the proposed 28/60-GHz compact antenna combines a meander-line monopole antenna with a packaging substrate. This study includes a built and tested 65-nm-bulk CMOS chip in addition to the antenna model and design analysis. At 28 GHz with a bandwidth of 5.3%, the prototyped on-chip antenna has a measured gain of -10 dBi, and at 60 GHz with a bandwidth of 5.9%, it has a gain of 0 dBi. At 28 and 60 GHz, the radiation efficiency is 45% and 30%, respectively. The antenna takes about 0.25 × 0.3 mm2 (43 x 35.7 at 28 GHz) of space. The general architecture of future wireless systems (5G and beyond) is highly desirable but problematic. The on-chip antenna approach in this paper hits the target of compatibility, cost, and compactness. Additionally, this work offers a workable design framework for future wireless systems that incorporate power harvesting, data transport, and sensing operations.

4.2.45 Paper 45

Single-Layer, Unidirectional, Broadside-Radiating Planar Quadrupole Antenna for 5G IoT Applications(2021): This [175] research presents a novel 28.475 GHz broadside-radiating unidirectional quadrupole-based antenna for 5G IoT applications. The planar antenna is based on single-layer technology to enable conformal applications and is produced on a flexible substrate. It comprises two quadrupolar near-field resonant parasitic (NFRP) elements and a coax-fed driven dipole. The unidirectional pattern produced by the broadside-radiating device has a front-to-back ratio of 9.4 dB and a realized gain of 4.85 dBi. The antenna's overall efficiency is 85%. A differential-fed prototype was developed, built, and tested to facilitate the measurements at 1.579 GHz. The results from simulation and measurement are well aligned.

4.2.46 Paper 46

Design and Implementation of Quad-Element Super-Wideband MIMO Antenna for IoT Applications (2020): A low profile, small, quad-port super-wideband (SWB) multiple-input, multiple-output (MIMO) antenna for the internet of things (IoT) applications is described in this paper [176]. The suggested antenna consists of four identical sickle-shaped resonating elements fired by feed lines that tapered coplanar waveguides (CPWs). To achieve high port isolation, the antenna elements are organized in rotational symmetry (mutually orthogonal to one another). A complimentary slot that matches the sickle-shaped radiator to achieve massive bandwidth is etched from the bottom of the suggested monopole antenna element. The MIMO antenna has a 31:1 bandwidth ratio and a resonating bandwidth (|S11| 10 dB) of 1.3–40 GHz. Additionally, the sickle-shaped radiator is given an L-shaped slit and a complementary split-ring resonator (CSRR) to block Bluetooth (2.4 GHz), WLAN (5.5 GHz), and downlink of X-band satellite communication (7.5 GHz) signals from the SWB.

4.2.47 Paper 47

IoT-Linked Integrated NFC and Dual Band UHF/2.45 GHz RFID Reader Antenna Scheme(2019): For Internet of Things (IoT) applications, this [177] research suggests a system board with an integrated antenna design for near-field communication (NFC) and dual-band ultra-high frequency (UHF, 920-925 MHz)/2.45 GHz RFID reader antennas. The NFC and UHF RFID modules, which are serially coupled to a microcontroller with a Wi-Fi module (NodeMCU), read the universal identification (UID) of NFC and UHF RFID tags when using the integrated antenna design to perform NFC and UHF RFID tasks simultaneously. Utilizing the Internet of Things (IoT), the data is sent to a cloud server, which can be viewed on Smartphone using the Blynk mobile application. The results of the simulation and the measurements coincide well. The dual-band UHF/2.45 GHz RFID reader antenna reaches the 920-925 MHz and microwave (MW) bands with good isolation, while the NFC reader antenna resonates at 13.56 MHz. The suggested integrated NFC and UHF RFID antenna architecture is unusual in that real-time and historical data are stored in the cloud rather than on conventional servers. The NFC, UHF, and MW frequency bands may all be achieved via the combined antenna design, making it perfect for Internet of Things applications.

4.2.48 Paper 48

A Modified Meander Line Microstrip Patch Antenna with Enhanced Bandwidth for 2.4 GHz ISM-band Internet of Things (IoT) Applications (2019): In this study [178], a modified meander-shaped microstrip patch antenna for 2.4 GHz ISM (Industrial, Scientific, and Medical) applications is proposed. The antenna measures 40 by 10 by 1.6 millimeters. The antenna consists of a slotted rectangular box connected to an inverse S-shaped meander line. The design incorporates a parasitic patch with a shaped ground and a capacitive load (C-load). According to investigations, the inverse S-shaped patch and rectangular box microstrip line antenna has greater efficiency and gain than the typical meander-shaped antenna. To match the impedance, the C-load is applied to the feed line. The parasitic element's 12.5% influence on the antenna's bandwidth is significant. The finished antenna has a 2.4 GHz radiation efficiency of 79% and a measured peak gain of -0.256 dBi and 1.347 dBi, respectively.

4.2.49 Paper 49

Photovoltaic Cell With Built-In Antenna for Internet of Things Applications (2021): For Internet of Things (IoT) applications, a small, low-profile photovoltaic (PV) cell with an integrated antenna is presented in this study [179]. A hexagonal slot with a trapezoidal perturbation is cut from the PV cell's active region and bottom contact for resonance in the suggested design to use the gallium arsenide (GaAs)-based PV cell as an antenna. The ground plane for the antenna is likewise made from the bottom contact of the PV cell. A chip inductor serves as the circuit's RF choke, and an AC blocking circuit is employed to stop RF current from flowing toward the PV cell. As a result, a single device serves as both an antenna and a PV cell. Without an antireflection coating, the GaAs PV cell exhibits a power conversion efficiency (PCE) of 13.25%. Its open-circuit voltage (Voc), short-circuit current density (Jsc), and fill factor (FF) are each 0.963 V, 21.00 mA/cm2, and 65.52%, respectively. Additionally, the suggested PV-cell antenna has more than 90% optical transparency. The entire construction measures 31.4 mm by 33 mm by 0.639 mm (0.25 o, 0.26 o, and 0.0052 o at 2.45 GHz), and the antenna has a gain of 2.8 dBi at 2.45 GHz while operating in the 2.14 to 2.94 GHz band.

4.2.50 Paper 50

3D Printed Fingernail Antennas for 5G Applications (2020): Antennas on detachable fingernails for on-body communications at microwave and millimeter waves are suggested in this paper [180]. On an acrylonitrile butadiene styrene (ABS) detachable fingernail substrate, microstrip patch antennas have been directly printed using aerosol jet technology, a method for fine-feature material deposition. One that operates at 15 GHz and the other at 28 GHz have been printed and evaluated. The microstrip patch antennas and accompanying transmission lines were made using an Optomec device and nanoparticle conductive silver ink. A PulseForge device is then used to cure the inks. The millimeter wave antenna receives an additional copper layer during the electroplating process. Off-the-finger and on-the-finger simulations and measurements of the antennas have been done. There is good agreement between simulated and measured reflection coefficients (S11) and radiation patterns. The Internet of Things (IoT), where a significant amount of sensor data can be transferred at the microwave and millimeter wave spectrum of future 5G communications can use the suggested on-body antennas. Other electronic components, including on-body sensors, computational, storage, and communication systems, might be included in the detachable fingernails.

4.2.51 Paper 51

A Planar Low-Cost Electrically Small Antenna For NB-IoT Sensors (2020): The Electrically Small Antenna (ESA) is a low-cost planar antenna that is shown in [181]. Because the ESA was developed to function at 1.8 GHz, it is well suited for integration with Internet of Things devices that use the Narrow-Band Internet of Things (NB-IoT) protocol. An appropriate feeding structure is built with the assistance of characteristic modes to stimulate a magnetic mode that ultimately results in a horizontal omnidirectional pattern to make it possible for dependable power reception. The concept is implemented using the two layers of a commercially available low-cost substrate. It is fed with a balanced twin line arrangement to reduce common-mode radiation's impact. Both of these components are accessible at a cheap cost. The ESA has a simulated overall efficiency of 60%, an actual gain of -0.4 dB, and a ka value of 0.47. It can be easily integrated with electronics to provide a small communication system for the Internet of Things sensors, and this can be done without affecting the emission pattern of the antenna.

4.2.52 Paper 52

Design and Modification of multiband M-slot patch antenna for wireless applications (2020): In the study [182], a brand new design of multiband patch antenna (PA) with microstrip line feeding is given. In the beginning, a square-shaped antenna with an M slot edge on the patch layer was built, and the results in terms of gain, bandwidth, and return loss were recorded. It was suggested that improving the antenna's performance may be accomplished by making a modification that included cutting a rectangular slit into the ground layer. In the suggested design, a material made of copper was utilized for the patch and ground layers. In contrast, a material made of FR-4 epoxy with a thickness of 1.5 mm was employed for the substrate layer. FR-4 epoxy was used. The findings indicate that the M-slot patch antenna (MSPA) can function at 2.4 GHz, 4.55 GHz, and 7.63 GHz, which makes it suitable for Wi-Fi and Wi-max applications. On the other hand, the modified design has improved performance. It can function effectively at 2.4 GHz, 4.55 GHz, 7.63 GHz, 8.3 GHz, 9 GHz, and 9.9 GHz, making it suitable for additional wireless applications such as x-band satellite requirements.

4.2.53 Paper 53

Design and Performance Analysis of LoRa LPWAN Antenna for IoT Applications (2020): This study [183] presents a microstrip patch antenna that operates at 433 MHz for Low Power Wide-Area-Network. The substrate is FR4 (lossy), and the patch dimensions are 82.295 mm by 105.41 mm. By creating two T-shaped slots in the ground, the author of this research hopes to increase both productivity and gain. The Computer Simulation Technology (CST) studio suite was used to carry out the simulation.

4.2.54 Paper 54

A Design of ISM Band Transparent Metamaterials backed Dual Ring CPW Fed Antenna for IoT Applications (2021): Research [184] describes a CPW-fed transparent dual-ring antenna that has an Artificial Magnetic Conductor (AMC) backing it up. The twin ring transparent antenna has an impedance bandwidth and average gain of 5.46 - 5.96 GHz (8.8%) and 1.1 dBi, respectively. It is designed to resonate in the frequency spectrum of an ISM application and has a resonance frequency of 5.46 - 5.96 GHz. To increase the bandwidth and gain of the antenna, the AMC has been placed on the bottom side of the antenna. This is also where the analysis of modifying the AMC array components occurs. The use of AgHT-8 and Plexiglas, simulated by using CST software to check the antenna's performance in terms of its reflection coefficient, radiation pattern, and reflection phase, ultimately leads to the antenna and AMC structure having an overall transparent appearance. Impedance bandwidth and an average gain of 5.3 to 6.0 GHz (12.4%) and 5.47 dBi, respectively, are shown by a performance comparison between an antenna structure that does not incorporate an AMC array and an antenna structure that incorporates a 4 by 4 AMC array. This indicates that the latter structure is suitable for use in applications that involve the ISM band.

4.2.55 Paper 55

Compact Hybrid Energy Harvester Based on Transparent Dielectric Resonator Antenna for 5G-IoT Applications (2020): A portable hybrid energy harvester based on a dielectric resonator antenna (DRA) is shown in paper [185]. In the 5G-IoT application scenarios, it gathers 2.45 GHz radio frequency (RF) and light energy under dim illumination of 200 lux to power expanded wireless sensor nodes. One piece of transparent hemispherical glass serves as both the antenna and the optical focusing lens. The solar cell is built inside the antenna to make the design more space-efficient, while the rectifier is placed underneath the ground. The simulations show that the hybrid energy harvester is dependent on luminous energy when the input RF power is about -30dBm, but that RF energy contributes significantly at -15dBm, accounting for 90% of the total at that point.

4.2.56 Paper 56

Dual Polarized Antenna Decoupling of Planar Antenna for 5G-NR Band N77 (2020): The dual-polarized antenna approach is proposed in the study [186] as a means of reducing coupling between MIMO antennas operating on the 5G-NR Band N77. The Rogers RT-5880 incorporates a kind of microstrip antenna inside the antenna. The antenna was redesigned to include a half-ground construction to achieve the greater bandwidth necessary to satisfy the 5G-NR Band N77. The antenna that was developed contains four components that are formed in a dual-cross polarized shape. The antenna has a coupling that is less than -17 dB. A low correlation is the result of poor coupling. The envelope correlation coefficient (ECC) obtained was less than 0.001.

4.2.57 Paper 57

Spider Web shaped Near-field UHF RFID Reader Antenna for Healthcare and IoT Applications (2020): The paper [187] describes and recommends using an antenna in a spider web in near-field UHF RFID applications. The open-ended microstrip lines are etched into the circular substrate, and the proposed design is a sequence of concentric decagons encircling the substrate. Because of the design that has been presented, the distribution of the electric field in the nearfield region is not only consistent but also highly robust. This may be seen as one of the defining characteristics of the nearfield region. This antenna also has low gain characteristics, which are necessary for most nearfield applications to avoid the inaccurate reading of other tags and safeguard against data corruption. It has a matching range between 902 MHz and 925 MHz frequencies, which corresponds to its impedance matching range. In addition, this design provides symmetric current distribution across the structure, which removes the challenges related to orientation sensitivity associated with low-cost linearly polarized tag antennas. The findings of the tests indicate that the tag can accurately read labeled drugs, expensive jewelry items, and tags that have been oriented in several different ways. Consequently, the reader antenna described is an outstanding candidate for near-field RFID, healthcare, and Internet of Things applications.

4.2.58 Paper 58

A Compact Omnidirectional Circularly Polarized Antenna (2021): A tiny loop antenna that is loaded with a 1/10 wavelength vertical stub is given as the compact omnidirectional antenna with circular polarization (CP) that is the focus of the research study [188]. The loop, made up of four bent dipoles and functions as an ideal magnetic dipole, produces a horizontal electric component. When the loaded stub is positioned in the center of the dipole arm, a vertical component with a phase difference of ninety degrees is attained. As a result, circularly polarized radiation is produced. A balanced parallel stripline provides the feeding for the antenna radiator. The prototype is etched on an FR4 substrate that is 30mm by 30mm, and then it is constructed and measured. Finally, comparisons between simulation and measurement are provided. At a frequency of 2.45 GHz, the results of measurements indicate that the recorded peak gain is -0.43 dB, and the polarization rejection ratio is 14.21 dB. Applications such as wireless measurement detection and Internet of Things applications are ideal for the loop antenna that has been developed.

4.2.59 Paper 59

A Frequency Tunable Hexagon Shaped Antenna for 5.8GHz-WiFi and Sub 6 - 5G Mobile IoT Applications (2021): This article [189] presents the design of a hexagon-shaped antenna that is capable of covering the 5.8GHz band for use in Wi-Fi applications and covering frequencies from 6GHz and higher up to 8GHz for use in 5G applications. Unit cells made of metamaterial (MM) are arranged around the intended antenna. There are five different metamaterial unit cells in operation, and three of the alternative MM unit cells are linked to the radiating element using PIN diodes. The antenna is kept partially grounded with a slot. The MM unit cells are arranged in hexagonal rings. As the substrate, Roger 3006 material that is flexible and has a thickness of 1.27mm and a dielectric constant of 6.15 is employed. The suggested antennas are evaluated for the frequency range of 4 GHz to 9 GHz. The comparative analysis is given with the assistance of the reflection coefficient, VSWR, radiation patterns, and other antenna characteristics under various switching scenarios.

4.2.60 Paper 60

Design of Wearable Reconfigurable Antenna for IoT Applications (2021): The Internet of Things (IoT) is a network that allows various electronic gadgets to communicate and work together. Antenna technology has only recently advanced, making wearable versions of the devices possible. These wearable antennas benefit significantly from the Internet of Things, energy harvesting systems, healthcare, and military use. This article [190] foresees a reconfigurable antenna with a wearable form factor. Depending on the situation, this antenna may switch its frequency. The suggested design's 40mm x 55mm dimensions are compact enough for use in modest settings. Three toggles allow for four distinct frequencies to be employed. The dielectric value of the Roger 6002 substrate is 2.94. Hence, it is utilized as a substrate. Between 2.5 GHz and 14.9 GHz, the resonant frequency may be found.

4.3 MOTIVATION

After reviewing these papers, we think 5G is the next big thing for the Internet of Things (IoT). It can bring a profound change in how we think about IoT. The number of IoT-connected devices is set to increase from 700 million to 3.2 billion by 2023 [191]. As we become more data-hungry, we will need to upgrade IoT technology to transfer more data. For that, 5G is the best possible solution. It is ten times faster than 4G and can transmit data at a rate of ten gigabits per second [192]. Based on this, we have decided to design an antenna for 5G-IoT applications. We aim to have it resonate in the FR-1 and FR-2 frequency bands.

4.4 AIMS AND OBJECTIVE

The aims and the objective of our research are given below

- To design a dual-band antenna.
- To resonate in the 5G's FR-1 and FR-2 ranges.
- To obtain a wide bandwidth.
- To create an antenna comparatively smaller in size.
- To achieve high efficiency.

4.5 PROBLEM STATEMENT

However, after reviewing these research papers, we have found that researchers have done some extraordinary work. Much research is based on GSM bands, sub-6GHz 5G bands, mmWave 5G bands, etc. A few papers also cover sub-6GHz and higher frequencies, i.e., frequencies greater than 24GHz. Although this research has some drawbacks,

- The overall size of their proposed antenna is comparatively larger. As a result, these antennas will be harder to implement or not be implemented in compact devices.
- Some research has performance issues, such as being less efficient, having a high reflection coefficient, etc.

4.6 IMPACT ON SOCIETY

5G will revolutionize the entire communication sector. While 4G was associated with the Smartphone generation, 5G will be associated with that generation and the development of smart industries, smart buildings, smart cities, etc.

A white paper published by the world economic forum states that By 2035, the global 5G value chain alone is projected to generate $3.6 trillion in economic production and 22.3 million employment thanks to intelligent internet connections made possible by 5G technology [193]. For a broad range of governmental, commercial, and industrial enterprises engaged in various mission-critical tasks, 5G continues to provide significant potential. These include linked digital gadgets, commonly known as the "internet of things" (IoT). High data speeds, decreased latency, energy savings, cost reductions, and better system capacity are projected to influence IIoT with 5G. Its potential to acquire large volumes of data from distant sensors and other linked devices will rocket the industry [194].

4.7 IMPACT ON THE NATURE

Some researchers have found that radiation caused by microwave frequency can heat our tissues. Also, some researchers claim that microwave frequencies could cause harm to the navigation process of birds [195]. However, many scientists rejected these claims. 5G's range and wavelength are short (high frequency). 5G's non-ionizing radiation. Ionizing radiation lacks the energy to extract electrons from atoms, breaking chemical bonds [196]. 5G's speed, capacity, and connection will present several options for environmental protection and preservation. The combination of 5G and IoT will boost energy efficiency, cut greenhouse gas emissions, and increase the usage of renewable energy. It may aid in the reduction of air and water pollution, the minimization of water and food waste, and the protection of animals. It may also deepen our knowledge of weather, agriculture, pests, industry, and waste reduction, enhancing our ability to make informed decisions. The combination of 5G and IoT will reduce energy consumption since gadgets will be able to turn on and off automatically. Sensors embedded in appliances, transit networks, buildings, factories, street lights, and other structures will automatically monitor and evaluate their energy requirements and consumption and optimize energy usage. For instance, intelligent power meters in the Empire State Building have contributed to a 38% reduction in energy expenses. GE's Digital Power Plant software is anticipated to decrease carbon emissions by 3 percent and coal use by 67,000 tons annually, given that conserving energy also implies reducing greenhouse gas emissions. According to research by Ericcson, a renowned supplier of information and communication technologies, IoT might reduce carbon emissions by 15% by 2030 [197].

Chapter-5
Design and Simulation Tools

5.1 INTRODUCTION

The core of simulation software is modeling a real-world event using a set of mathematical formulas. It's only a piece of software that attempts to simulate the real world so that the user may see a process in action without really having to do it. Designers often utilize simulation software to guarantee that the finished product nearly meets the planned specs. Real-time simulation software in gaming is standard, but it also has critical industrial applications. A simulation of the physical response in real time is linked to a replica of the actual control panel, providing valuable training experience without the risk of a disastrous outcome for professions where an error in operation could have severe consequences, such as airline pilots, nuclear power plant operators, and chemical plant operators. Modern software can model the operation of power grids, the weather, electrical circuits, chemical reactions, mechatronics, heat pumps, feedback control systems, atomic reactions, and even complex biological processes. In theory, computer simulations may be used to study any phenomena for which a sufficient number of mathematical facts and equations have been established [198]. The practice is not without difficulties due to the potentially infinite number of elements at play when modeling natural events. The success of a simulation may be significantly improved by identifying the factors that have the most bearing on the goals of the simulation. Hypotheses may be tested via simulations, and the system's behavior in many scenarios can be studied. Theorists may write computer programs based on the causal relationships they've identified. If the software accurately represents the behavior of the actual process, then the anticipated correlations are likely to hold. Over the last several decades, advancements in computer science have led to a dramatic improvement in the quality of computer simulations. Simulation technologies, which have their roots in a mathematical experiment conducted during World War II, are today used extensively in fields as diverse as medicine, manufacturing, and even the entertainment industry. Using simulation technologies in the classroom has resulted in many positive outcomes and benefits. Improvements in computing will lead to more immersive simulations, further revolutionizing pedagogical tools [199].

5.2 WHY WE USE SIMULATION

Imitation is used extensively in product development because it speeds up the process, reduces costs, and improves dependability. When thinking about the bucket, think about this. If the manufacturer selects a plastic without first simulating its performance, the bucket may break under the water's weight, pressure, or temperature. The handle might break at the worst possible moment if it's poorly designed. Since information about the properties of various plastics is readily available, the simulation may help manufacturers choose the best plastic to employ before they ever make a physical prototype of a bucket. What supposing someone fills the plastic bucket with heavy oil? How much weight can it support? Thanks to precise modeling, manufacturers can now tell consumers with 100% accuracy how much weight the bucket can handle. This is but a bucket, after all. The complexity of most things in the actual world exceeds that of a bucket. Complex systems, such as automobiles, cranes, airplanes, and even military missiles, may benefit significantly from modeling and simulation throughout the design phase. Each product has hundreds of components that must work together to provide the desired results. There is a risk that the whole system may be rendered inoperable if even a single component fails. Only via simulation can we test the mechanism's robustness and find methods to improve its performance. Altair's specialized software and other advancements in computer technology have made simulation a snap. These days, when people talk about a "simulation," they nearly always mean a computer simulation [200].

Performing in-depth analysis of complex, real-world products is impossible without proper modeling and simulation. What about if anything were to fall from a height of 5 meters? A jet moving at 575 km/h will meet turbulence; what will happen to it? Is it possible for a ship to endure winds of forty knots or more? Using simulation and modeling tools like Altair FluxTM, AcuSolveTM, FEKOTM, OptiStructTM, RadiossTM, and activate, you can receive exact answers to all these questions without spending a ton of money on developing prototypes. It's a valuable tool for managers coordinating the creation and upkeep of complex systems. Complex problems cannot be investigated, analyzed, or evaluated without simulation software [201].

Companies in the manufacturing, design and engineering sectors have found simulation to be an effective tool for staying ahead of the competition because of its endeavor to reproduce the natural world as precisely as possible. A key advantage of simulation is that it frees the design team to focus on creating the "right" system, technique, or product rather than being constrained by financial constraints. Second, they may dwell on whatever went wrong throughout the design process by revisiting it several times (like watching simulation films)—after that, rerunning the experiment with minor adjustments would be simple. At least in the prototype stage, one of the most typical simulation software uses is to try out alternative values for the model's parameters to see which works best [202].

5.3 SIMULATION SOFTWARE FOR ANTENNA

Various software is currently used to do the simulation task for antenna and microwave .some of them are ZELAND IE3D, Ansoft HFSS, Microwave Studio CST, FEKO, Antenna Magus, etc. The selection of simulation software depends mainly on the structure's geometry and the required accuracy of the solution. Although CST is reliable, HFSS is preferable for designing flat antennas like Microstrip antennas. While FEKO is the superior choice when dealing with reflectors, CST is the better choice when dealing with more generic and straightforward scenarios due to its superior accessibility. So we selected CST as the primary antenna design and simulation tool.

5.4 CST MICROWAVE STUDIO 2018

CST STUDIO SUITE® 2018, the company's best electromagnetic (EM) simulation software, has been updated to the 2018 version. Dassault Systèmes own the SIMULIA brand, and CST is a part of that brand. CST STUDIO Package is a popular electromagnetic (EM) simulation software suite used by industry leaders to create, test, and improve systems and components across the EM spectrum. Thanks to the CST® Complete Technology approach, there are strong connections between the different solvers, and you can access them all from a single GUI. CST STUDIO SUITE 2018 is better than the versions that came before it because it has several new tools for modeling complex systems using hybrid methods. The System Assembly and Modeling tool in CST STUDIO SUITE is a powerful way to combine the results of several simulations with different solvers (SAM). As of this year (2018), Assembly Modeler gives users access to a unique 3D environment that makes it easier to put together complicated models from separate parts. The Hybrid Solver Task helps hybrid simulation move forward by letting the Time Domain Solver and the Integral Equation Solver talk back and forth. Because it is now part of the CST STUDIO SUITE interface, clients can use the voxel poser tool at any point in the modeling process. Using tetrahedral mesh body models to simulate breathing accurately is crucial for medical devices. Filter Designer 3D, a tool from CST that lets you make cross-coupled filters and figure out-coupling matrices, has been added to the advanced optimizers in the suite. So, optimizers may now be able to use the coupling matrix calculation, which makes filter tuning faster and more accurate. With CST STUDIO SUITE, customers can use a new alternative interface for photonic and terahertz applications to get instant access to optical properties. It is now possible to use wavelength instead of frequency to run simulations. CST STUDIO SUITE 2018 adds a new way of calculating far-fields on multiple layers of substrates. This is useful for photonics and modeling antennas built on complex printed circuit boards. The integration of CST STUDIO SUITE with the Dassault Systèmes 3DEXPERIENCE® platform is being made so that it can connect to more SIMULIA tools, and the software that runs on top of it is constantly updated so that it works best on the latest hardware [203].

Chapter-6
Methodology and Antenna Designing Steps

6.1 INTRODUCTION

Methodology is the study of research techniques. The word, however, may also be used to designate the processes themselves or the philosophical interpretation of the underlying premises. A method is a deliberate approach for reaching a certain goal. This purpose is frequently to develop new information or confirm statements made by pre-existing knowledge in a research environment. This often involves a number of steps, including as choosing a sample, collecting data from this sample, and analyzing this data. The study of methods includes a comprehensive description and assessment of various processes. It also includes evaluative elements, such as evaluating alternative approaches to find out their advantages and disadvantages for specific research goals and situations. By advising researchers on the best approach to use at each stage, a technique may help to make the research process dependable and effective. These method evaluations and descriptions frequently include assumptions about philosophy. The assumptions are about things like how to think about the topics being examined, what counts as evidence for or against them, and what the main purpose of the research is. Considering these more esoteric concerns falls within the broadest definition of methodology.

Several thinkers have cited the methodology as crucial for several concerns. For instance, a thorough comprehension of it could facilitate researchers' speedy development of trustworthy hypotheses. Depending on the approach adopted, the same factual information in certain situations might result in different conclusions. The 20th century has seen a massive increase in interest in methodology. This may be due, in part, to the fact that many of the global issues facing modern civilization may only be resolved via multidisciplinary research. Such joint efforts are aided by methodological advancements, which make it simpler for researchers from one discipline to comprehend how their colleagues from another field arrive at knowledge. However, other critiques of the approach have also been made. Specific methodological outlooks target many criticisms, such as those that prioritize quantitative research. Some of the objections are more extensive in that they disapprove of methodology as a field in general. Some detractors think it is pointless since techniques should be used instead of studied. More extreme critics see technique as damaging, for instance, because it limits the researchers' flexibility and creativity or because thinking critically about procedures might result in more errors than just following them blindly.

6.2 DESIGN OF THIS RESEARCH

The overall approach to conducting research that offers a logical framework for data collection, assessment, analysis, and discussion is known as research design. A research study's design is determined by the researcher's perspectives on reality and knowledge, which are influenced by their field of study [204][205].
The research design for this research work is given below:

- Study on 0G to 5G.
- Study on 5G and Its requirements and frequency band for the antenna.
- Do a literature review on 5G and existing 5G antennas.
- Select two 5G frequency bands.
- Go through the procedure of antenna design.
- Calculate necessary parameters to design antenna.
- Design the antenna in CST Microwave Studio.
- Simulate the antenna in software and Collect the best result.

6.4 ANTENNA DESIGN PROCEDURE

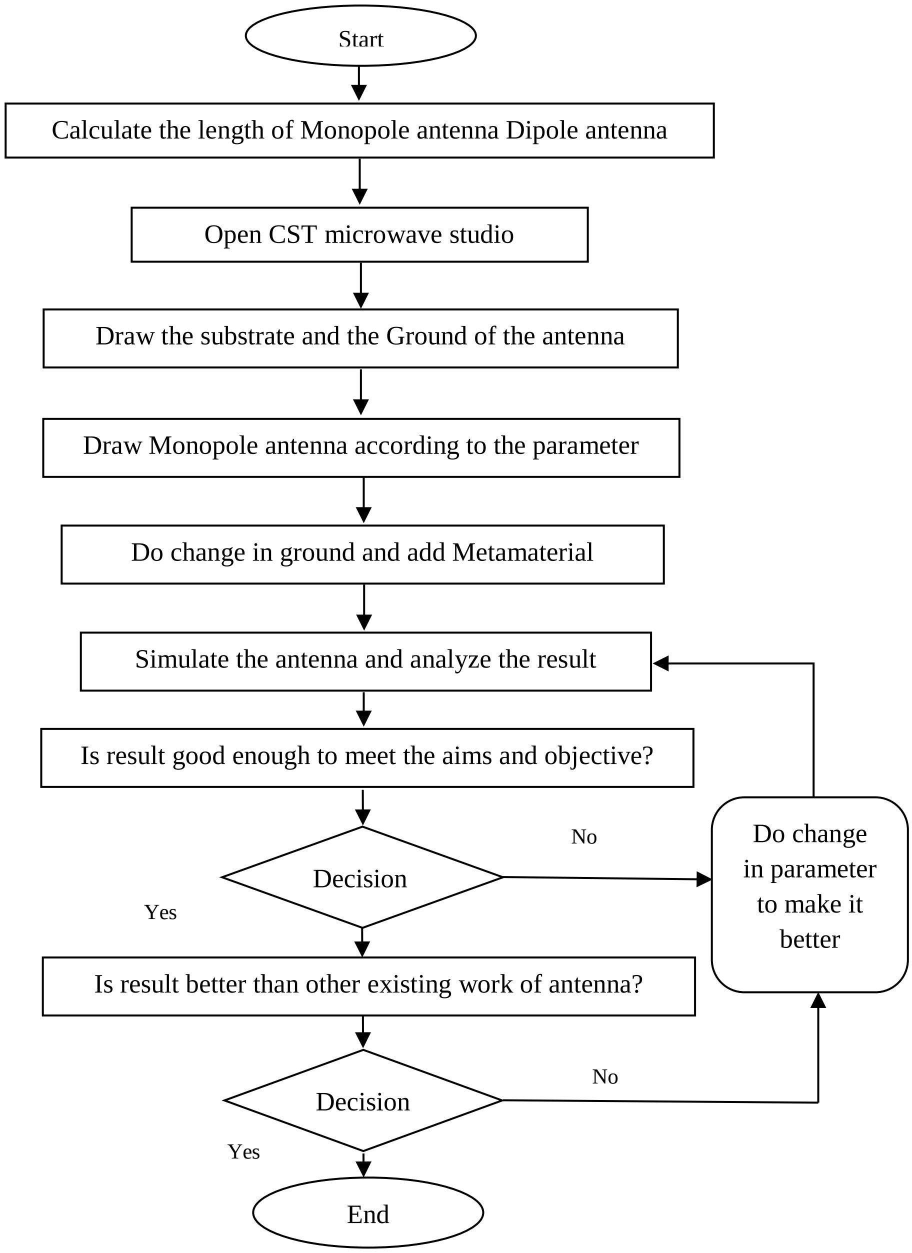
In this section, we describe the antenna designing procedure of this research work,

6.4.1 ALGORITHM AND FLOW CHART

The algorithm for the design of the antenna is given below -

Step 1: Start.
Step 2: Select two frequencies; One from FR1 and another from FR2.
Step 3: FR1 for a monopole and FR2 for a dipole antenna.
Step 4: Calculate the Length of the monopole and the dipole antenna.
Step 5: Take a ground and set a substrate on the ground
Step 6: Set the monopole antenna patch on the substrate.
Step 7: Add a feed line for the antenna.
Step 8: Now set the dipole antenna.
Step 9: Set the parameter again to find the expected result.
Step 10: Stop at the best result.

The flow chart for the design of the antenna is-



6.4.2 FREQUENCY SELECTION

We have selected the two frequencies, one from FR1 and another from the FR2 range.

6.4.2.1 FREQUENCY RANGE 1

For the Lower range of our antenna, we have selected 5 GHz as the center frequency. This frequency can be used for IoT using Wi-Fi protocol [208] [209].

6.4.2.2 FREQUENCY RANGE 2

For the higher range of our antenna, we have select 28GHz as the center frequency. A lot of paper has been published where they designed antenna for IoT at 28GHz some of them are [210]-[214].

6.4.3 ELEMENT SELECTION

6.4.3.1 PATCH

We use copper as the patch of the antenna. Copper is a highly conductive material used in the design and fabrication of microstrip antenna because of its availability and low cost. The thickness of the copper plane is 0.035mm. The conductivity of copper is 5.96×10^{7} S/m at 20° C temperature [206]

6.4.3.2 GROUND

The ground material of the antenna is also copper, and the thickness of the copper is the same as the patch, which is 0.035 mm.

6.4.3.3 SUBSTRATE

The substrate used in this antenna is Rogers RT/duroid 5880LZ. According to the company datasheet, the Dielectric Constant of this material is 2.00 ± 0.04. The Rogers Corporation provides 0.252 mm as standard thickness, so we use this thickness to design the antenna [207].

6.4.4 MATHEMATICAL EQUATION

The mathematical equation that is used to find out the primary parameter of the antenna is given below-

6.4.3.1 MONOPOLE ANTENNA

The equation of monopole antenna is –

$$\mathbf{L}_{\text{Monopole}} = \frac{c}{4f_c\sqrt{(\varepsilon_r+1)/2}} \quad \text{(i)}$$

6.4.3.2 DIPOLE ANTENNA

The equation of Dipole antenna is-

$$\mathbf{L}_{\mathbf{Dipole}} = \frac{\mathbf{0.4\ c}}{f_r\sqrt{\varepsilon_{eff}}} \quad \text{(ii)}$$

Here,

$$\boldsymbol{\varepsilon_{eff}} = \frac{\varepsilon_{r+}1}{2} + \frac{\varepsilon_{r+}1}{2}\left(1 + \frac{10H_s}{W}\right)$$

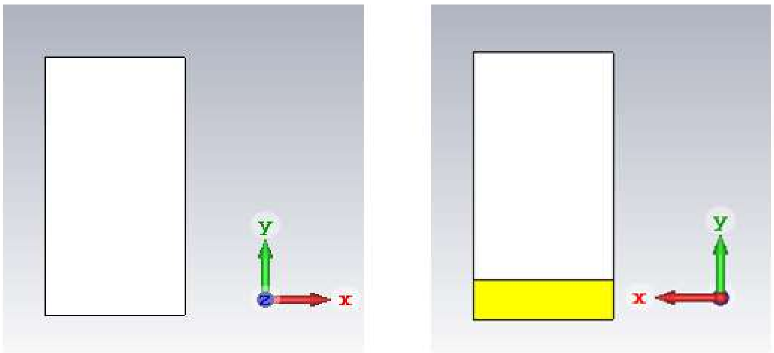
Where,

H_s = Height of substrate;

W = The width of the patch;

6.5 ANTENNA DESIGNING STEPS

1) Substrate and Ground: Build the substrate with dielectric and the ground copper material. The Ground is in the back side of the antenna.



a b

Figure 6.1: Substrate and Ground Design .a) Front view, b) Rear view.

2) Feed line: Build the feed line in the front side of the antenna.

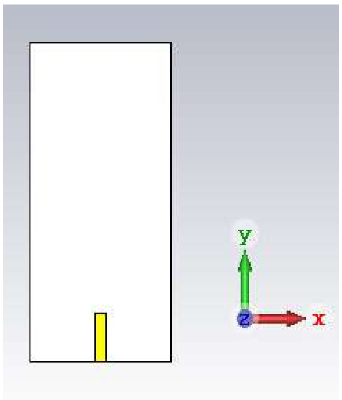
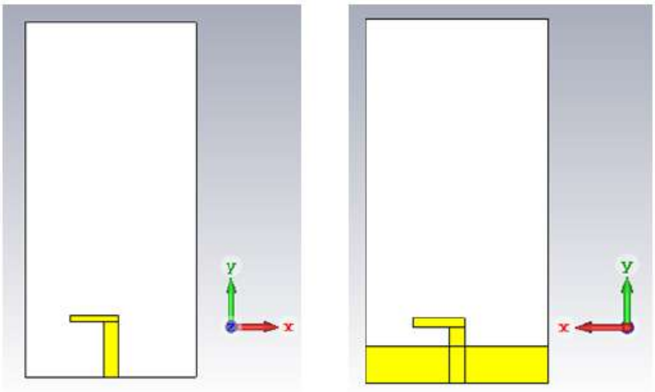


Figure 6.2: After adding Feed line.

3) Dipole: After build the feed line of the antenna, Build the Dipole antenna.



a b

Figure 6.3: After Adding Dipole, a) Front view, b) Rear View.

4) Monopole: After build the dipole design the monopole in front side of the antenna.

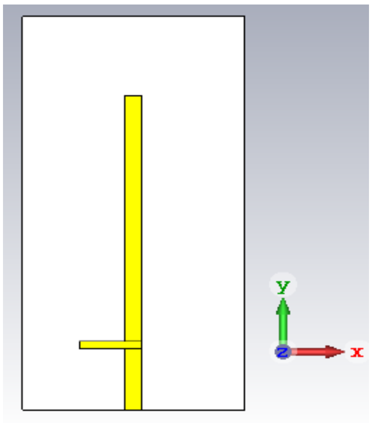


Figure 6.4: After Design Monopole.

5) Parasitic Element: Add Parasitic Element in the back part of the antenna.

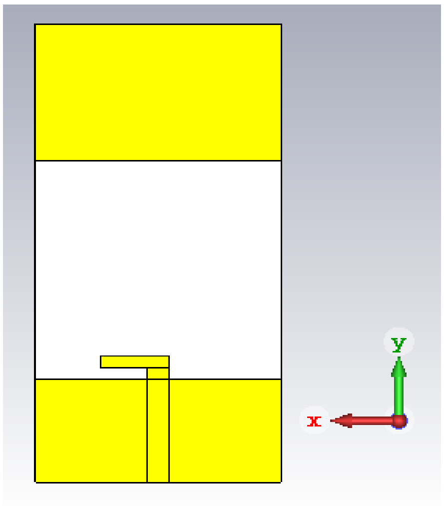


Figure 6.5: After add Parasitic Element.

6.6 FINAL DESIGN AND PARAMETER OF PRPOSED ANTENNA

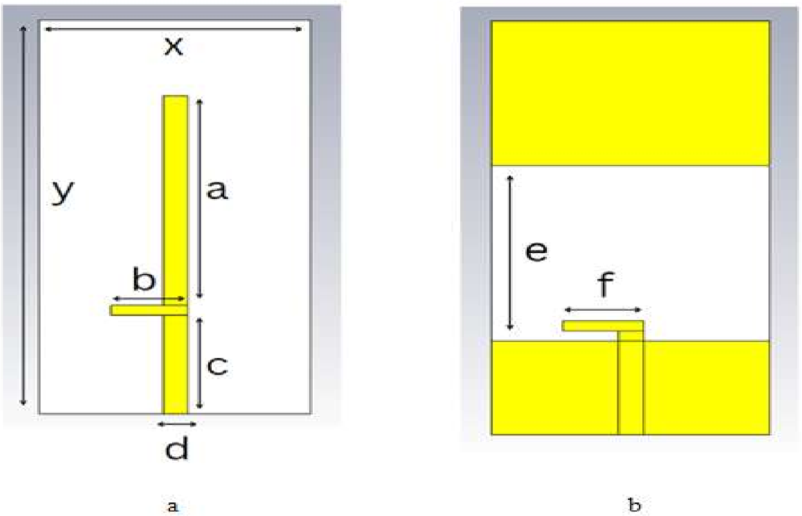


Figure 6.6: Proposed antenna a) front View, b) Rear view.

Table 6.1: List of parameter

Symbol	Value (mm)	Description
a	10.65	Length of Monopole
b	2.825	Length of Dipole In front side
c	5	Length of Feed line
d	0.9	Feed line Width
e	8.5	Gap Between Ground and Parasitic Element
f	2.92	Length of Dipole in Rear side
x	10	Substrate Height
y	20	Substrate Width

Chapter-7

Antenna Simulation and Result Analysis

7.1 INTRODUCTION

In the chapter we will discuss about the simulation result of the proposed antenna .From the result of the simulation, we can understand the characteristics and performance of an antenna.

7.2 ANTENNA PERFROMENCE PARAMETER

7.2.1 RESOANTING FREQUENCY

The resonating frequency is the operating frequency of antenna that means in which frequency the antenna delivered maximum power to the patch. From Figure 7.1 we can see that the resonating frequency of the antenna is 5GHz and 28GHz.

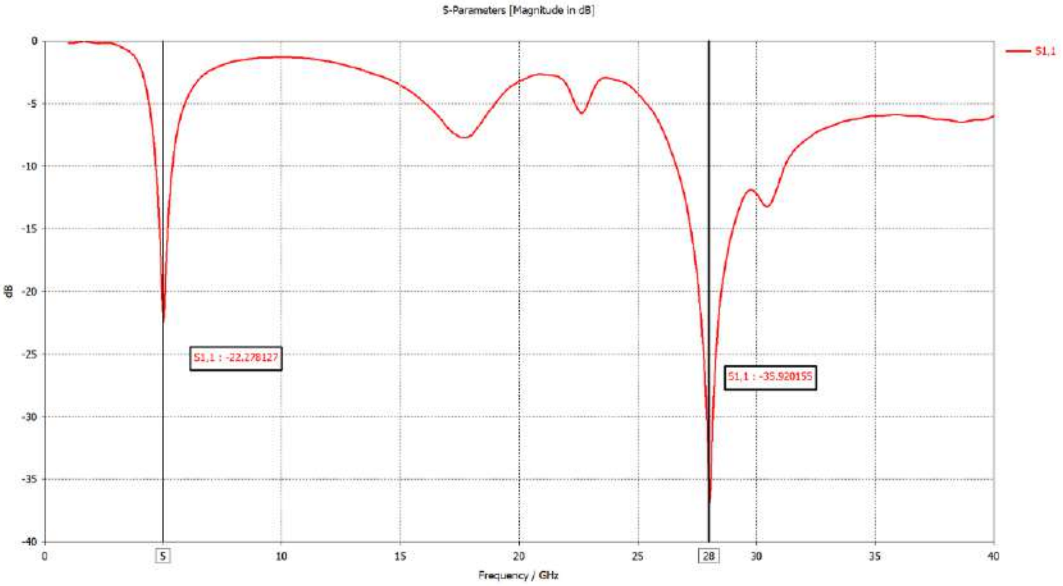


Figure 7.1: Resonating Frequency

7.2.2 RETURN LOSS (S11)

The reflected power from an antenna is determined by return loss [215]. The return loss (S11 parameter) is the most fundamental parameter for evaluating an antenna's performance. Figure 7.2 and Figure 7.3 shows the return loss plots for the 5GHz and 28GHz antenna. The antenna's return loss values at 5GHz and 28GHz are roughly 22.278 dB and 35.920 dB, respectively.

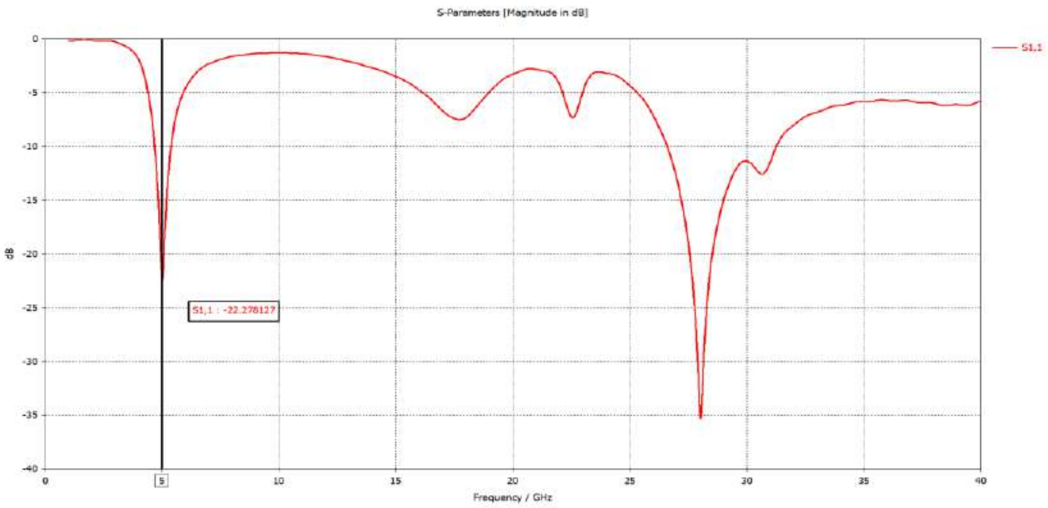


Figure 7.2: S11 for 5GHz Frequency.

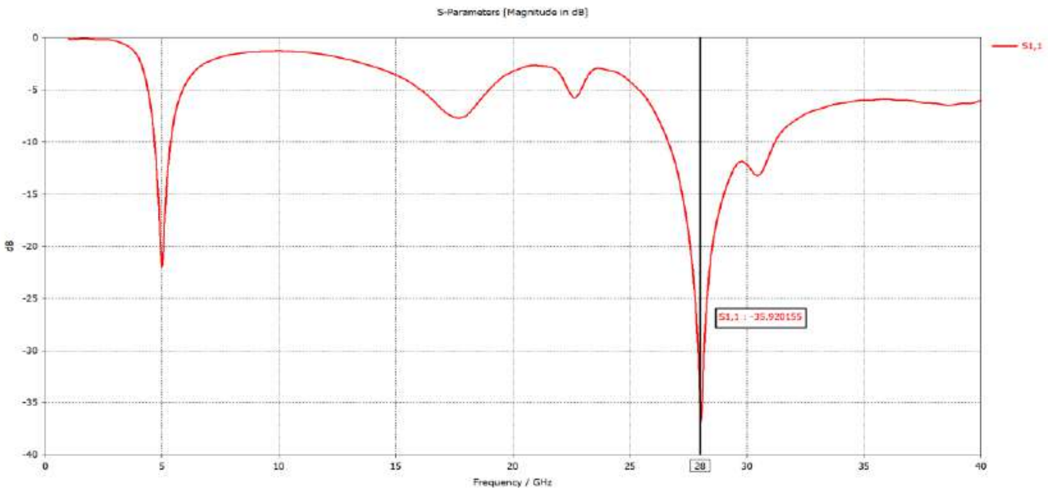


Figure 7.3: S11 for 28GHz Frequency.

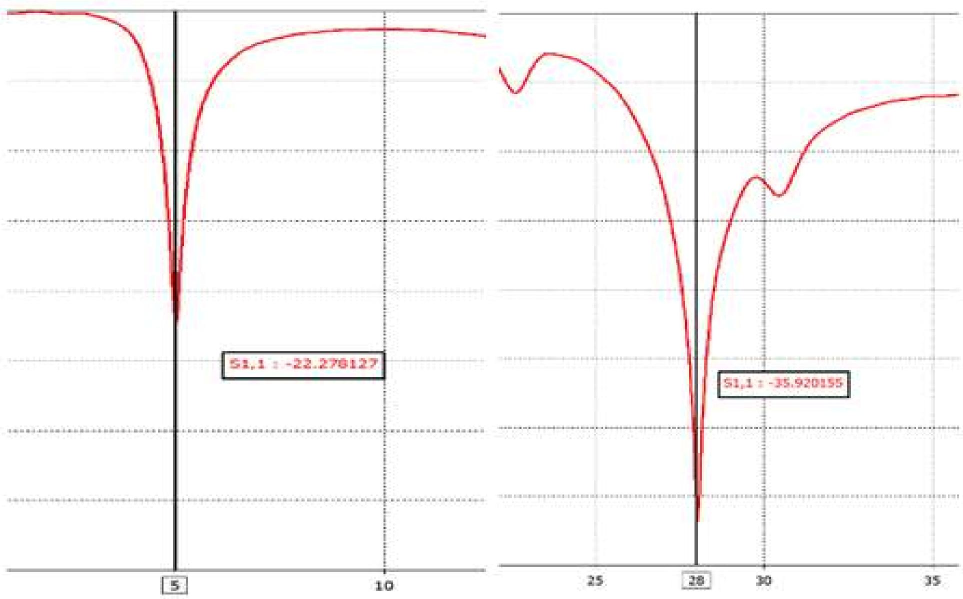


Figure 7.4: Clear View of S11 for Both 5GHZ and 28GHz.

7.2.3 VOLTAGE STANDING WAVE RATIO (VSWR)

Another measure used to determine the antenna's impedance match is the VSWR. It is, in fact, a determinant of load impedance matching to a transmission line's characteristic impedance [216]. Figure 7.5 and Figure 7.6 shows a VSWR vs. frequency plot in the frequency bands of 5GHz and 28GHz, with an expected value of 1 to 2. As seen in Figure 7.7, at 5GHz and 28GHz, the VSWR values are 1.178 and 1.028, respectively. The suggested antenna's VSWR value is within the standard limit for the operational frequency range, indicating that the antenna is very efficient.

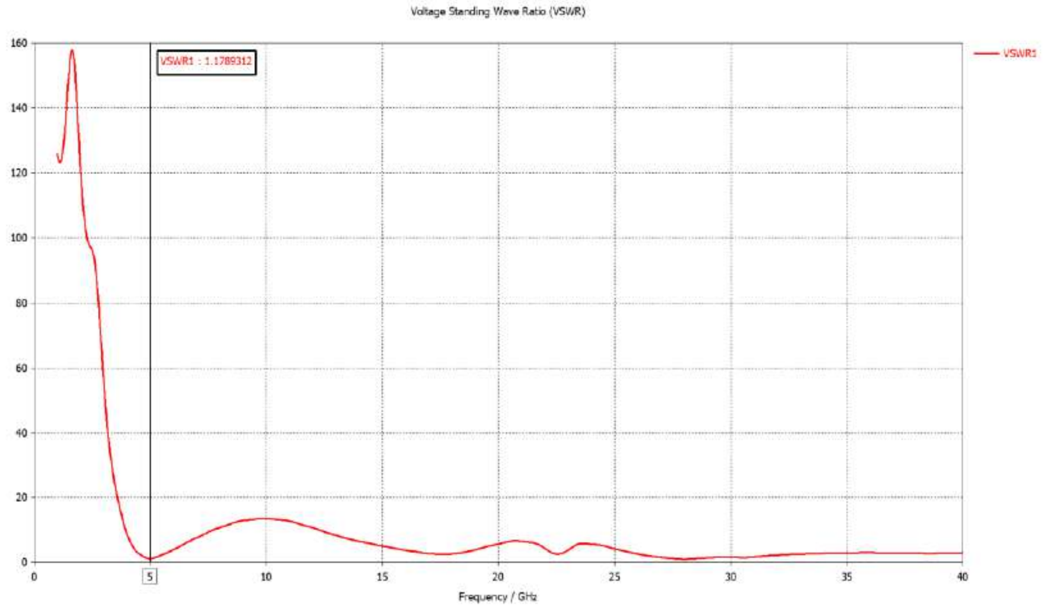


Figure 7.5: VSWR for 5GHz.

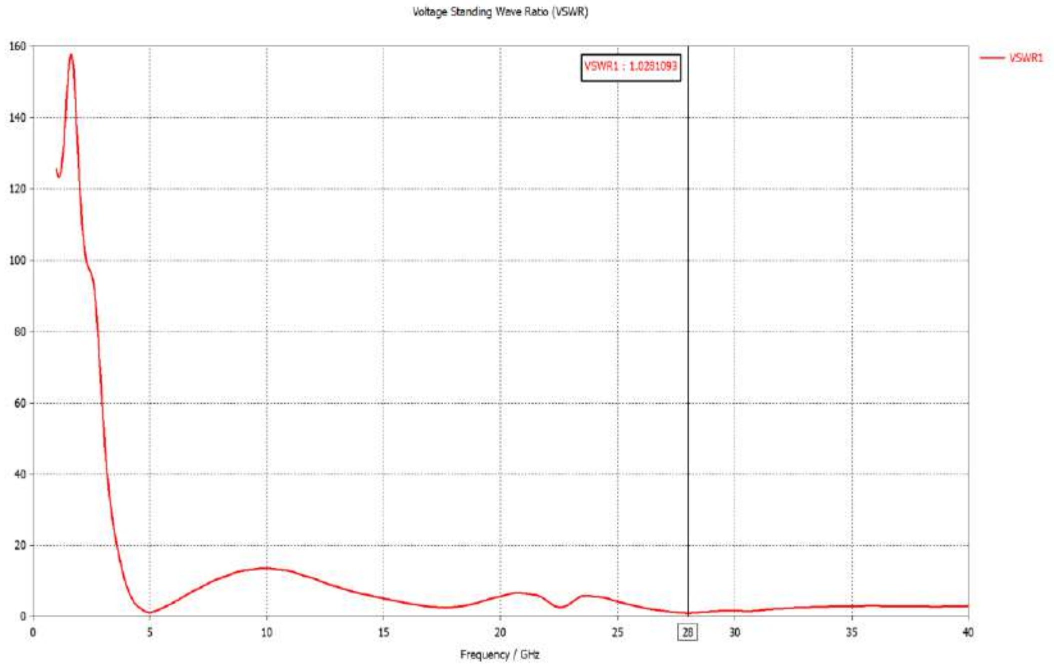


Figure 7.6: VSWR for 28GHz.

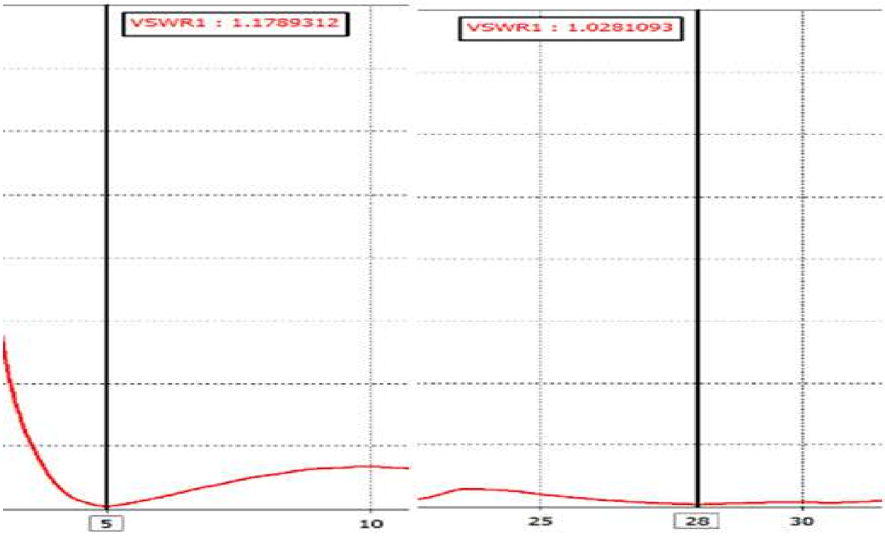


Figure 7.7: Clear View of VSWR for Both 5GHz and 28GHz.

7.2.4 RADIATION PATTREN

The visual illustration of an antenna's radiation characteristics is known as the radiation pattern [217]. Radiation patterns are the graphical indication of how radiated energy is dispersed in space as a function of direction. The antenna's far-field area shows this power fluctuation as a function of the arrival angle. The radiation patterns can be three-dimensional or two-dimensional. The three-dimensional (3D) radiation pattern makes it simple to monitor the power supplied in a specific direction.

7.2.4.1 DIRECTIVITY

The directivity of an antenna is a property that quantifies how concentrated its radiation pattern is in a given direction [218]. Directivity is quantified in dB. The higher the directivity, the more concentrated or directed the antenna's beam is. If the directivity is higher, the beam will go further. Figures 7.8 and Figure 7.9 depict the antenna's three-dimensional radiation pattern at 5GHz and 28GHz.and Figure 7.10 shows that for 5GHz and 28GHz, the maximum directivity is 1.922 dBi and 7.469 dBi, respectively.

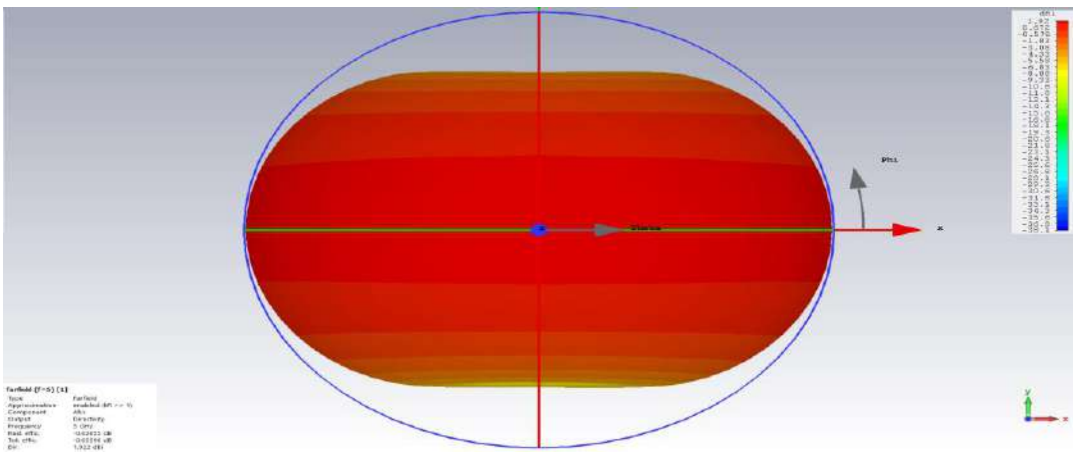


Figure 7.8: Directivity at 5GHz.

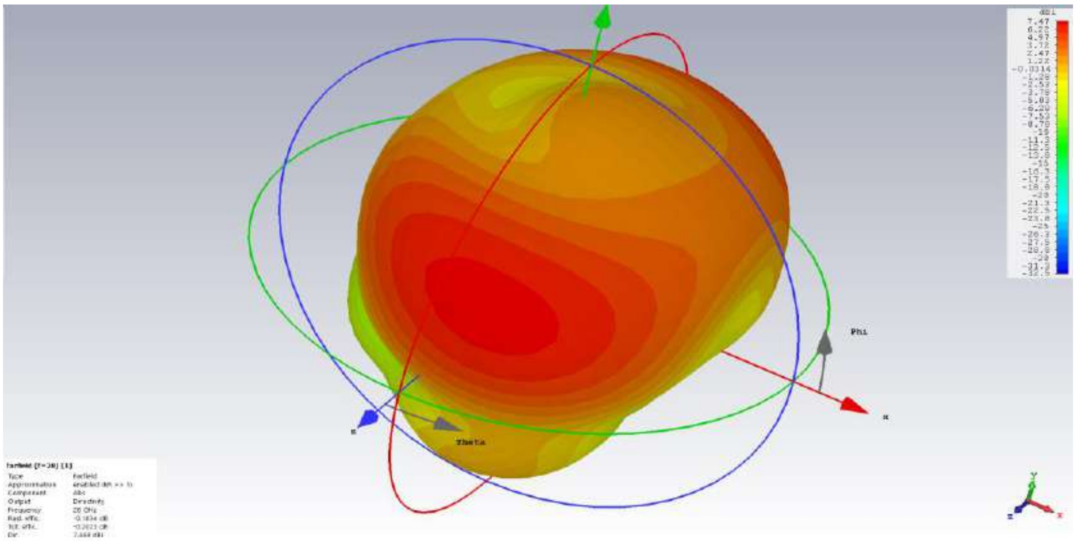


Figure 7.9: Directivity at 5GHz.

farfield (f=5) [1]		farfield (f=28) [1]	
Type	Farfield	Type	Farfield
Approximation	enabled (kR >> 1)	Approximation	enabled (kR >> 1)
Component	Abs	Component	Abs
Output	Directivity	Output	Directivity
Frequency	5 GHz	Frequency	28 GHz
Rad. effic.	-0.03655 dB	Rad. effic.	-0.1834 dB
Tot. effic.	-0.05598 dB	Tot. effic.	-0.2023 dB
Dir.	1.922 dBi	Dir.	7.469 dBi

Figure 7.10: Clear View of directivity of 5GHz and 28GHz.

7.2.4.2 GAIN

Antenna gain is the amount of power that is transmitted from an isotropic source to the direction of the peak radiation. Because it compensates for actual losses, antenna gain is referenced more frequently than directivity on antenna specification sheets. Figures 7.11 and Figure 7.12 depict the antenna's three-dimensional radiation pattern at 5GHz and 28GHz. Figure 7.13 shows that for 5GHz and 28GHz, the maximum gain is 1.866 dB and 7.266 dB, respectively

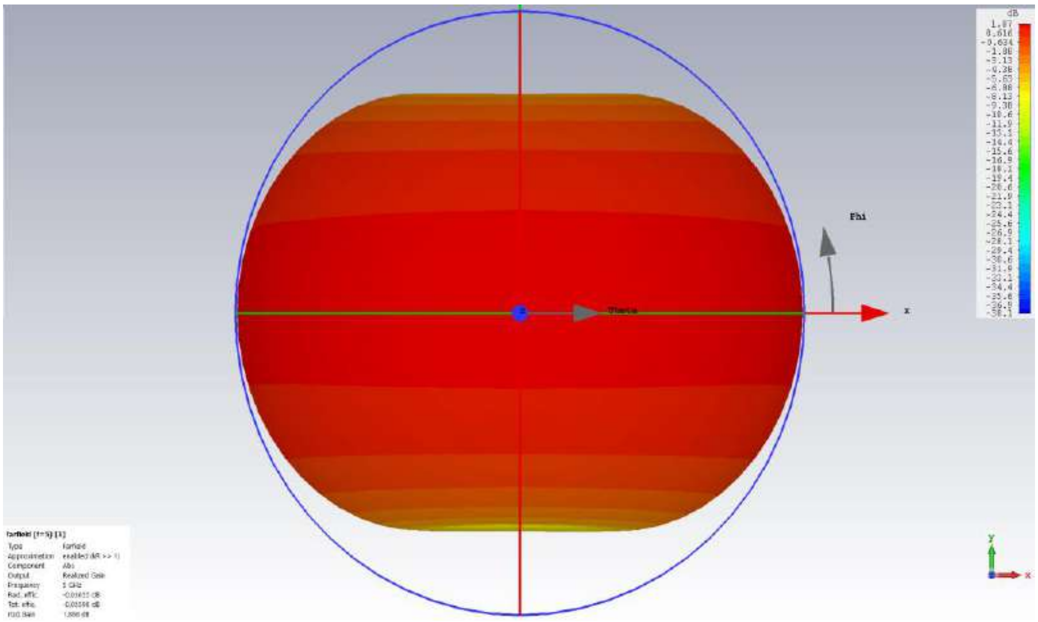


Figure 7.11: Gain at 5GHz.

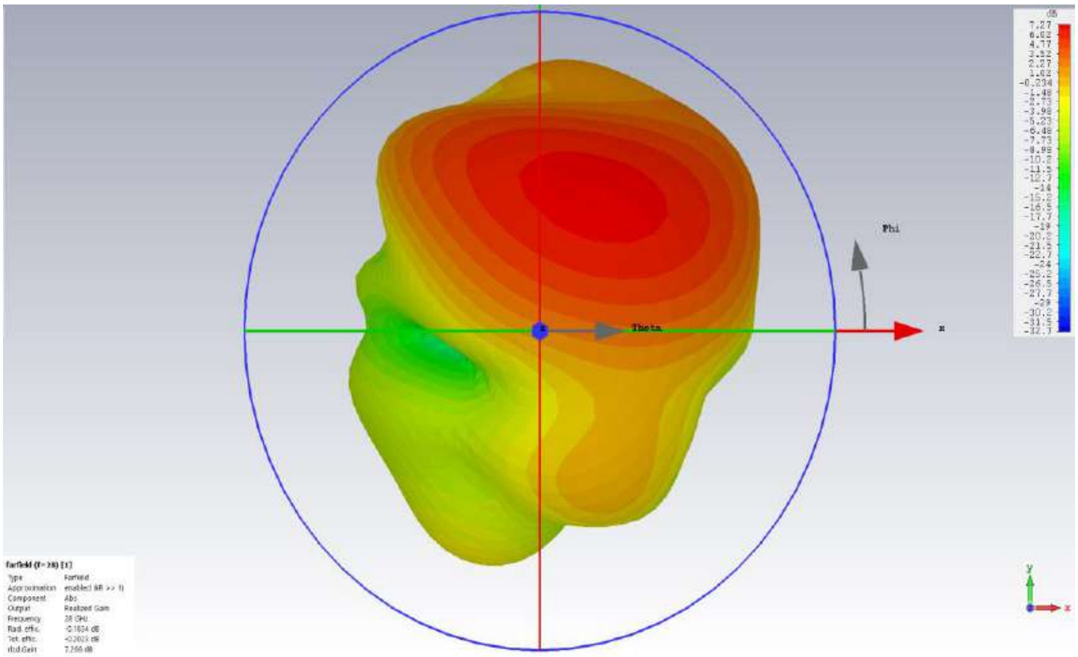


Figure 7.12: Gain at 28GHz.

farfield (f=5) [1]		farfield (f=28) [1]	
Type	Farfield	Type	Farfield
Approximation	enabled (kR >> 1)	Approximation	enabled (kR >> 1)
Component	Abs	Component	Abs
Output	Realized Gain	Output	Realized Gain
Frequency	5 GHz	Frequency	28 GHz
Rad. effic.	-0.03655 dB	Rad. effic.	-0.1834 dB
Tot. effic.	-0.05598 dB	Tot. effic.	-0.2023 dB
rlzd.Gain	1.866 dB	rlzd.Gain	7.266 dB

Figure 7.13: Clear view of gain at 5GHz and 28GHz.

7.2.4.3 TWO DIMENTIONAL RADIATION PATTERN

Figure 7.14 and Figure 7.15 shows the 2D radiation pattern of the proposed antenna.

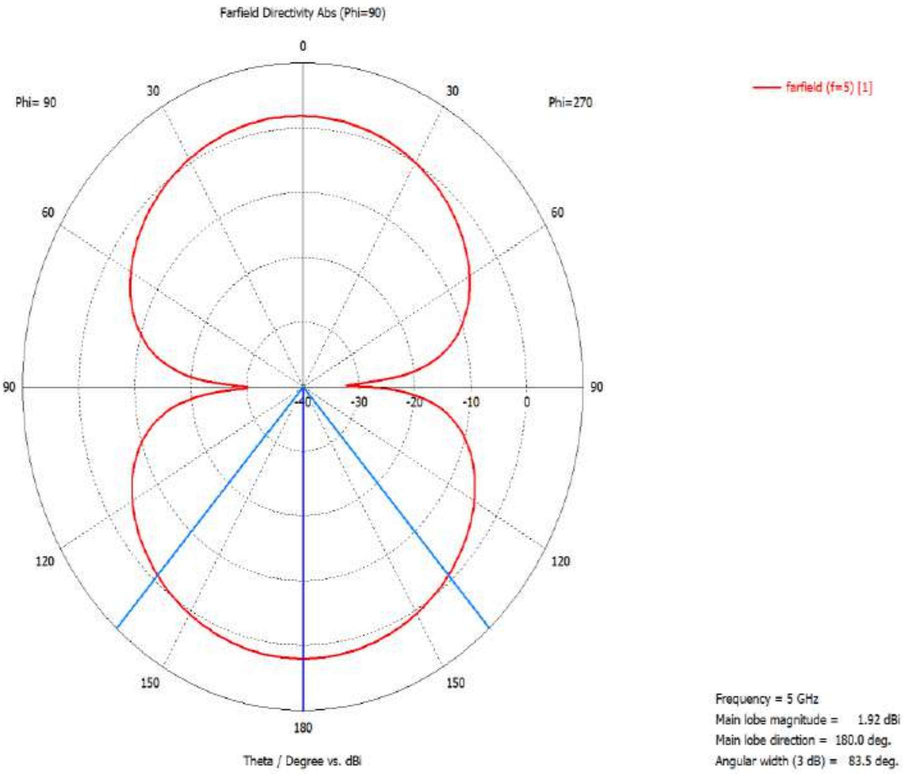


Figure 7.14: 2D Radiation pattern of 5GHz.

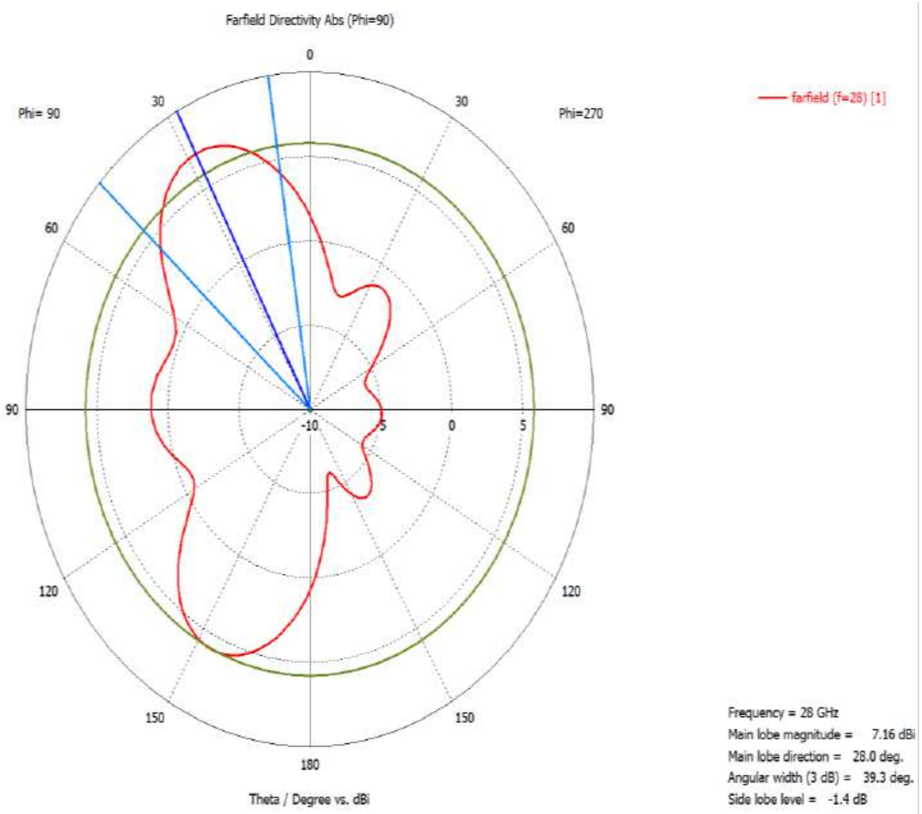


Figure 7.15: 2D Radiation pattern at 28GHz.

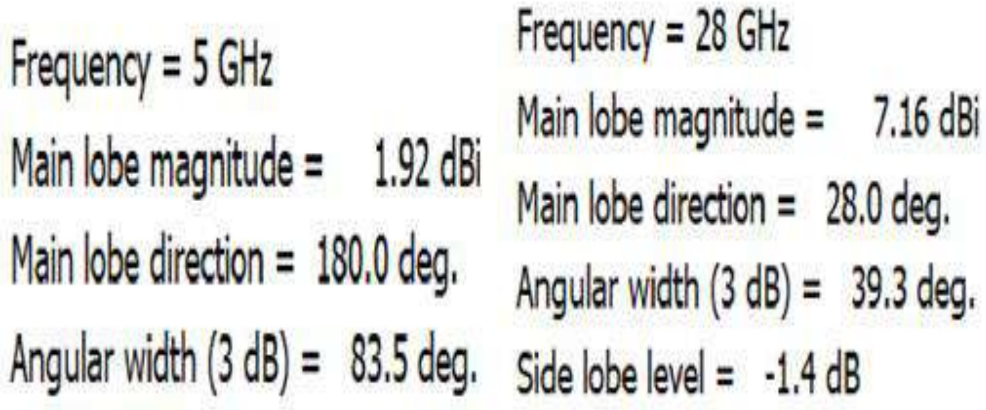


Figure 7.16: Clear View of 2D radiation pattern at 5GHz and 28GHz.

7.2.5 BANDWIDTH

The frequency range across which an antenna can function properly is referred to as its bandwidth. The intended bandwidth is frequently one of the deciding factors when choosing an antenna. For instance, several antenna types cannot operate in wideband mode due to their extremely limited bandwidths [220]. In addition, at 5GHz, the -10 dB bandwidth is around 0.7015GHz or 701.5MHz, while at 28GHz, it is around 4.672 GHz.

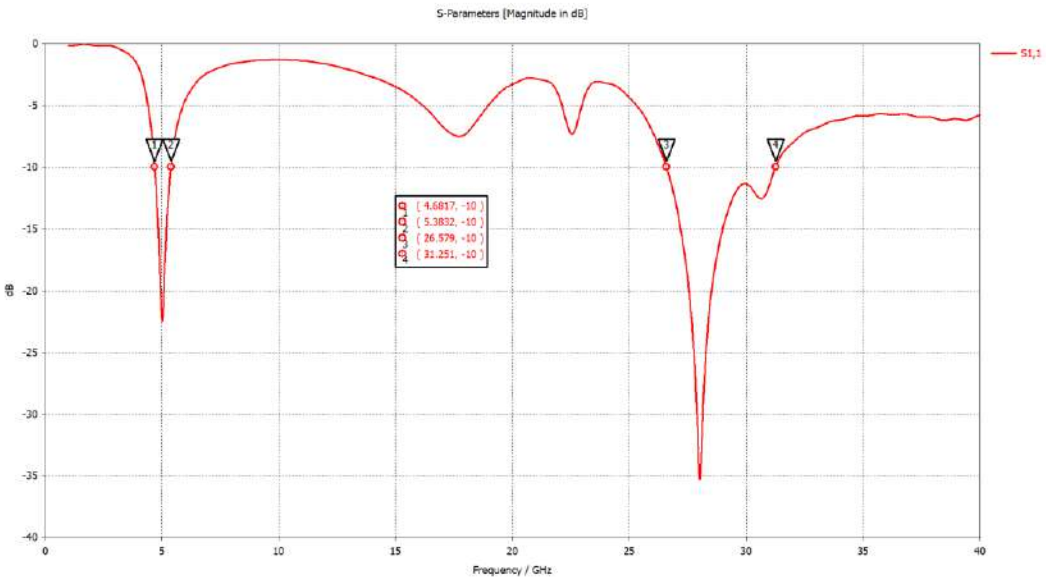


Figure 7.17: Bandwidth of antenna.

7.2.6 EFFICIENCY

An antenna's efficiency is determined by its radiated output power ratio and inserted input power. Typically, the efficiency of mobile phone antennas or Wi-Fi antennas in consumer electronics goods range from 20% to 70% [221]. However, it is always preferred to achieve the efficiency near to 100. As shown in figure 7.18 and 7.19, at the frequencies of 5GHz and 28GHz, antennae have 92.34 percent and 95.84 percent efficiency, respectively. The antenna's higher efficiency demonstrated that it is radiating at its best.

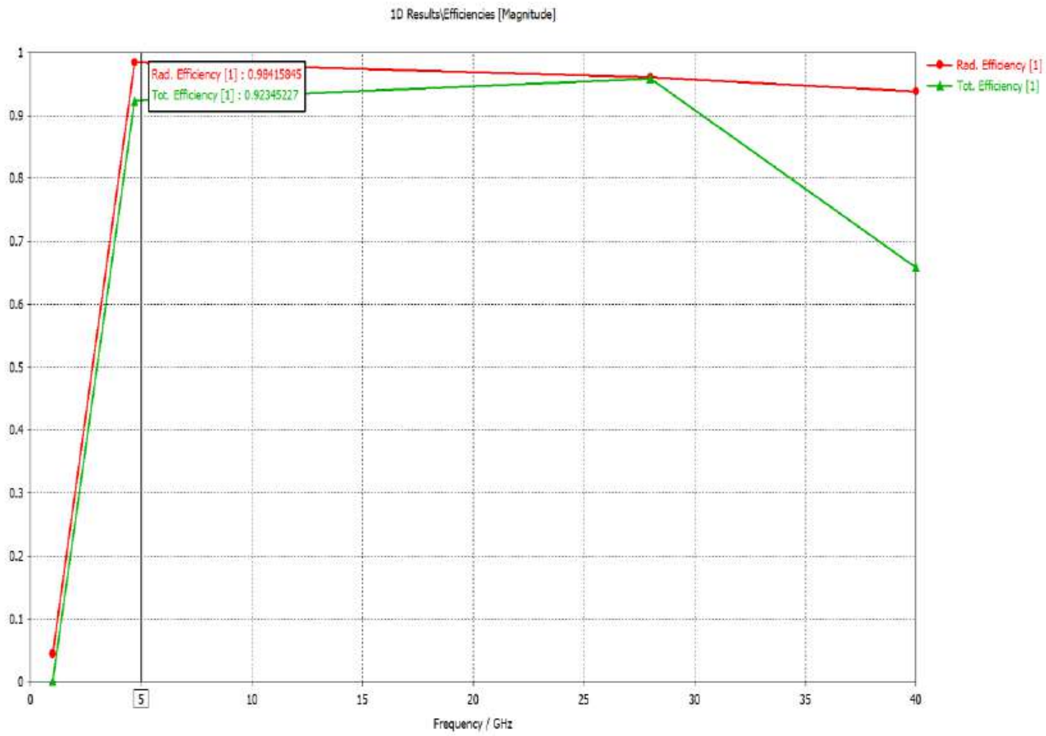


Figure 7.18: Efficiency at 5GHz.

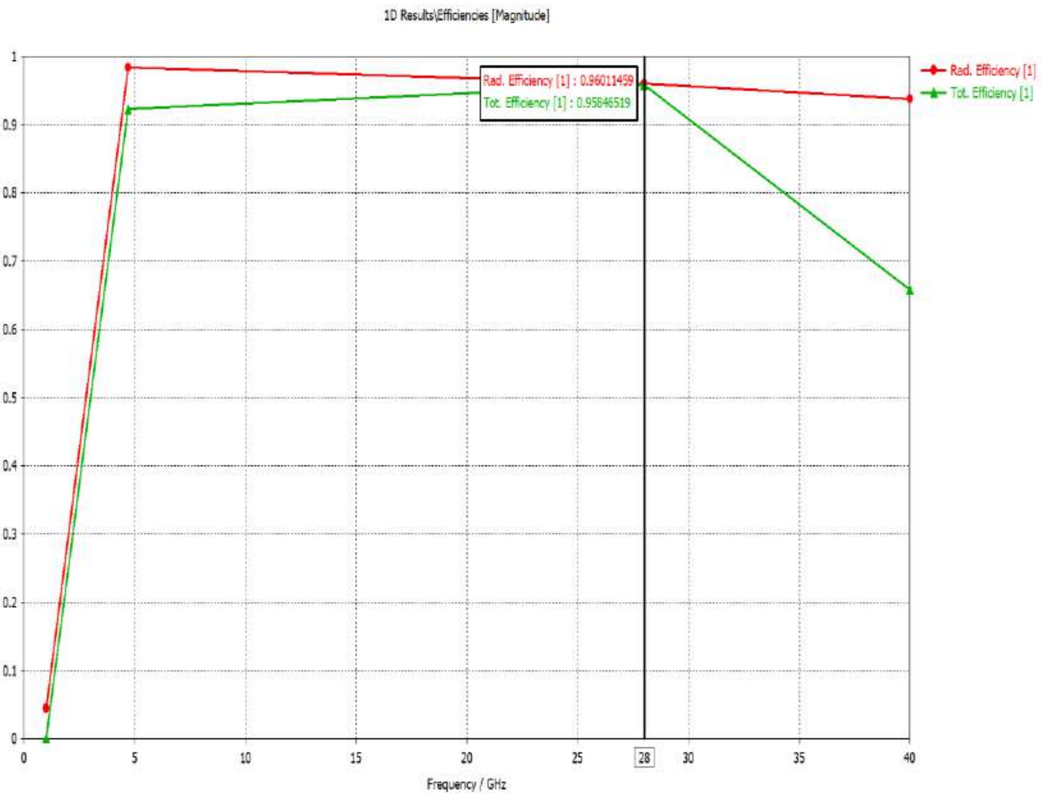


Figure 7.19: Efficiency at 28GHz.

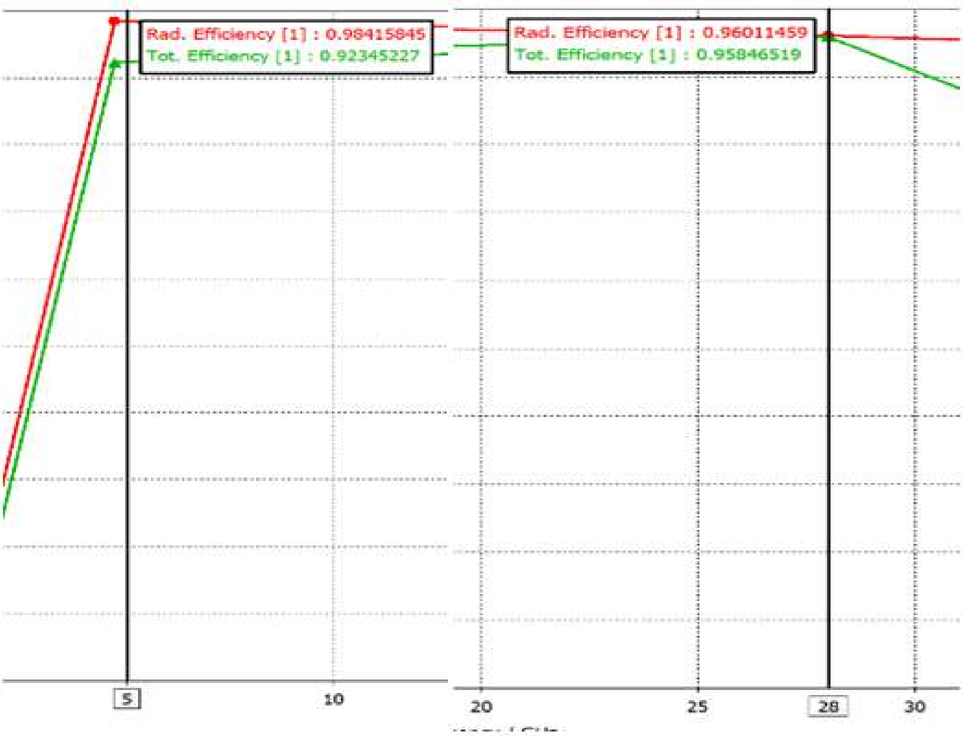


Figure 7.20: Clear view of Efficiency at 5GHz and 28GHz.

7.2.7 CURRENT DISTRIBUTION

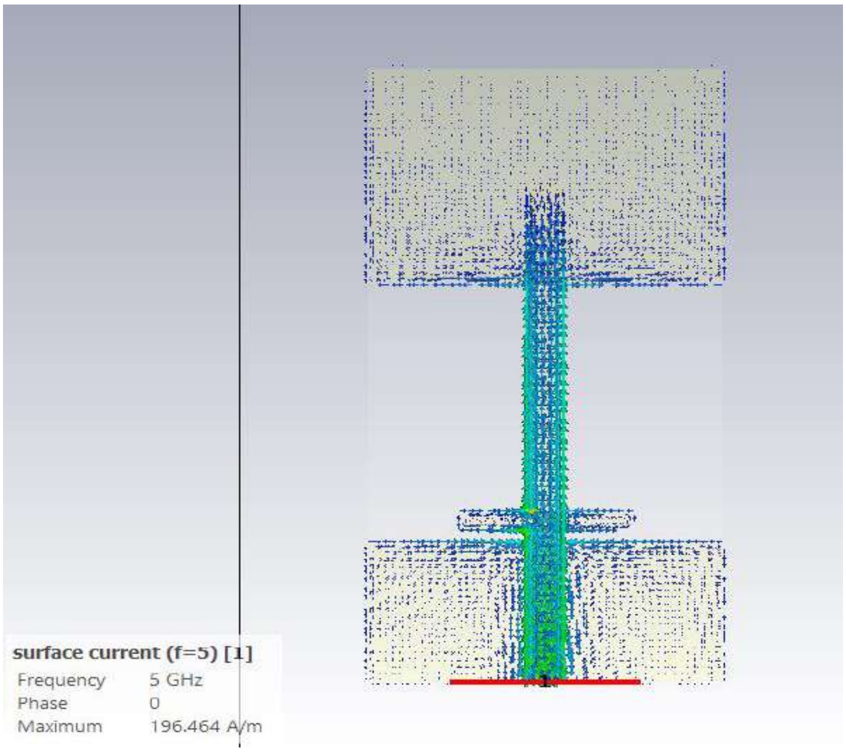


Figure 7.21: Current distribution of antenna at 5GHz.

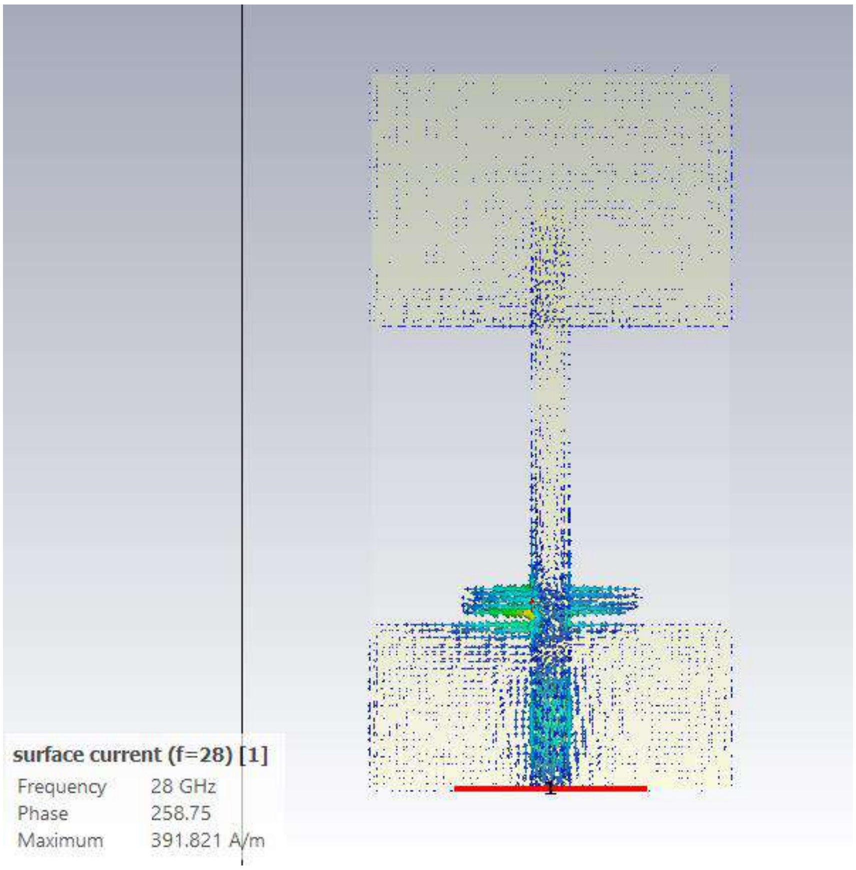


Figure 7.22: Current distribution of antenna at 28GHz.

7.2.8 REFERENCE IMPEDANCE

The below Figure 7.23 shows the reference impedance of antenna which is 50 Ohm.

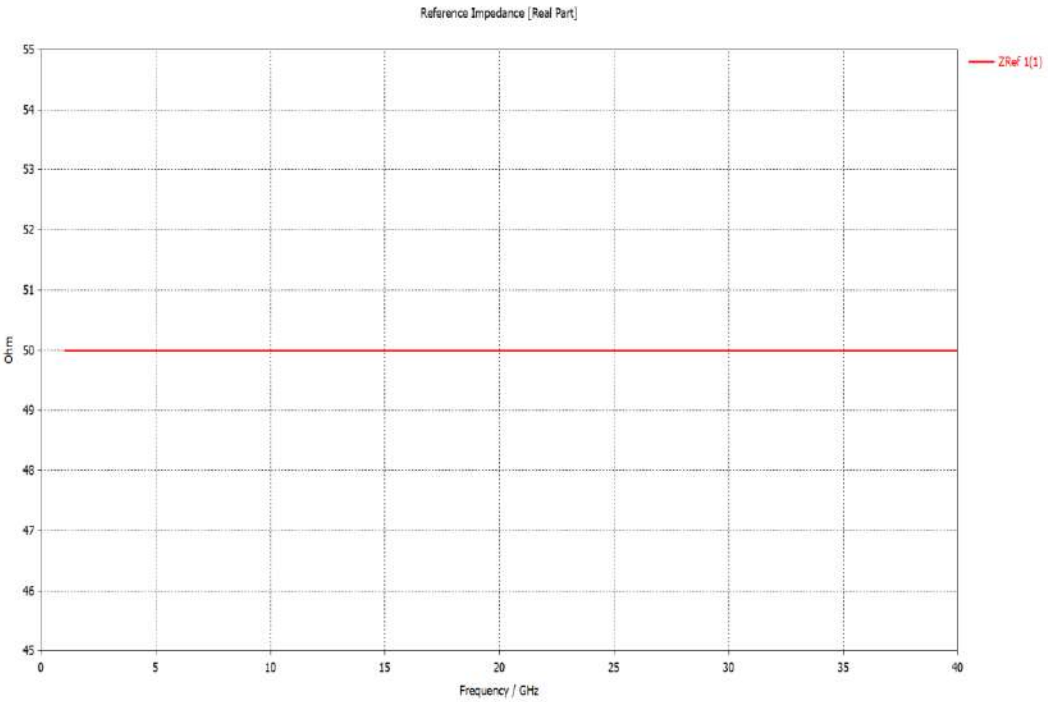


Figure 7.23: Reference Impedance of the antenna.

7.3 FINAL TABLE OF PERFORMANCE PARAMETER

Table 7.1: Final performance parameter.

Parameter	Value at 5GHz	Value at 28GHz	Standard
Bandwidth	701.5MHz	4.672 GHz.	As required
Return loss (S11)	22.278dB	35.920dB	Above 10 dB [222]
VSWR	1.178	1.028	1-2 [222]
Gain	1.866dB	7.266dB	As required
Directivity	1.922dBi	7.469dBi	As required
Efficiency	92.34 %	95.84 %	20% to 70% [221]

7.4 COMPARISON WITH OTHER SIMILER WORK

Table 7.2: Comparison with the existing works

Ref	Antenna type	Resonant frequency (GHz)	Size (mm^3)	Peak Gain(dBi)	Return Loss (Above 10db)	Efficiency
[132]	Triple-band	3.8 5.5 26/28	110 × 75 × 0.508	3.27 5.41 10.29	√	71 79 60-70
[139]	Multiband	(2.46–2.49) (5.0–6.3) (23–28)	30×30×0.508	3.55 4.72 5.85	√	N/A
[141]	Dual band	5.8 28	18 × 16 × 0.285	1.55 5	√	N/A
[141]	Triple-Band	3.5 5.8 28	30 × 25 × 0.543	1.86 2.55 4.41	√	97.8% 98% 97%
[143]	Multiband	3.6 28	75×25×0.254	8dBi (at 28GHz)	√	65%-90%
[144]	Dual-band	(3.2-4.05) (26.8-29.55)	N/A	7.27 to 10.44 11.8 to 14.6	√	61%
[146]	Dual-band	3.5 28	33.9×43×0.25	7.07dBi 11.31dBi	√	N/A
[151]	Dual-band	(1.870–2.530) 28	60×100×0.965	4.42 10	√	N/A
[156]	Multiband	2.4 5.5 28	45×40×0.508	1.95 dBi 3.76 dBi 7.35 dBi	√	N/A
This work	**Dual-band**	**5** **28**	**20×10×0.322**	**1.866dB** **7.266dB**	√	**92.34 %** **95.84 %**

Chapter-8
Achievements and Future Work

8.1 THESIS SUMMARY

In this thesis, we have reviewed several observations on dual-band antennas for 5G applications. Our main focus was to design a compact antenna with great results. We classified our thesis into eight chapters. In the first chapter, we have discussed the fundamentals of wireless communications. We focused on the history of wireless communication, the use of wireless communication, different multiple access techniques, wireless network standards, and wireless network generations. Lastly, we have briefly discussed the fifth generation of wireless communication. In the second chapter, we have discussed the Internet of Things (IoT). Here, we have mentioned the history of IoT, how it works, components to implement it, requirements, and network protocol. At the end, we have discussed the importance of 5G for IoT devices and applications. In the third chapter, we have discussed the fundamentals of antenna and propagation. Here, we have talked about the working principle of an antenna, types of antenna, and frequency range of operation. We have briefly talked about dipole antennae, monopole antennae, loop antennae, aperture antennae, microstrip antennae, etc. We have also discussed the performance parameters like bandwidth, reflection coefficient, VSWR, radiation intensity, beamwidth, directivity, gain, and antenna efficiency. In the fourth chapter, reviewed literature is discussed. After the literature review, we have mentioned the motivation, aims, and objectives of our research. We have also discussed the impact of our research on society and the environment. In chapters five and six, the design, simulation, and antenna design steps are discussed. In chapter seven, the results found from the simulation are discussed. We have also compared our results with other research.

8.2 ACHIEVEMENTS AND FINDING

After reviewing almost sixty research papers, we have found that most of the research is not compact and cannot be implemented in a compact device if possible. So we have made it our goal to design a compact antenna while keeping performance good. And after completing the research, we have achieved our goal. Our antenna has a size of only 200 mm^2 and an efficiency of over 90 percent for all resonating frequencies. We have achieved good reflection coefficient value, VSWR value, directivity, etc.

8.3 CHALLENGES & LIMITATION

During this research, we have faced a few challenges. After completing the design, we did not have any opportunity to fabricate the antenna. Because there are some factors that can affect performance in a real environment that are not possible in simulation, and this is the only limitation we have during our research.

8.4 FURURE WORK

The designed and simulated antenna should be fabricated in order to evaluate real-world performance and compare simulation results to measurements.

8.5 CONCLUSION

In our thesis, we have started our discussion with the fundamentals of wireless communication. We talk through the history of wireless communication, its standard, network protocol, etc. Then we talked about the importance of IoT and its applications and protocols. After that, we talked thoroughly about antenna and propagation. Thereafter, we have talked about the reviewed literature and the findings from those papers. We have addressed the issue of those research papers (if any) and stated our overall goals. Based on our goal and the findings, we have started our design process. We have initiated with the measurement found in the design equations. We tested different designs and selected the one that is presented earlier in this thesis. Afterwards, we optimized the parameter measurements to achieve the best result possible. Finally, at our operating frequencies, we have achieved 92.34 percent and 95.84 percent efficiency, respectively. In conclusion, we have shown an antenna that can be used for 5G applications, especially for the Internet of Things (IoT).

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