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Design of a miniaturized Millimeter-Wave antenna for 5G Wireless Networks

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Dedication

This thesis work is devoted, first and foremost, to all of our wonderful parents and respected instructors.

Certificate of Approval

The thesis titled **"A miniaturized millimeter-wave Antenna Design for 5G Wireless Communication"** Submitted by **Yeasin Arafath Munna** bearing **Matric ID: T181068**; **Mohammed Mohsin Faisal** bearing **Matric ID: T181063**; of Academic Year 2022, Session: Autumn 2022 has been found as satisfactory and accepted as partial fulfilment of the requirement for the B.Sc. in the Department of Electronic and Telecommunication Engineering on International Islamic University Chittagong**.**

Candidates Declaration

The work contained in this thesis has not been submitted anywhere for a degree or certificate and does not include any illegal statements.

Mohammed Mohsin Faisal

T181063

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Abstract

In this research, a microstrip patch antenna was designed for high-speed data transmission at 5G using millimeter waves (mm waves) in the frequency range of 40 to 75 GHz (V band). The suggested antenna has been developed with an operating frequency of 46.44 GHz. Research on the 5G Band, which spans the frequency range of 45.5 to 52.6 GHz is still in its early stages. Like all other millimeter wave bands 45.5 to 52.6 GHz band is also designed for transmitting and receiving data across short distances at high speeds. The proposed antenna is on a Roggers 5880 substrate that is 0.5 millimeters thick. The dielectric constant of the substrate is 2.3, and the loss tangent is 0.0009. The projected antenna has a gain of 6.1 dBi and a directivity of 6.7 dBi for a single element, and it has a wideband characteristic of roughly 4.5 GHz. The VSWR is 1.0019, and the return loss is somewhat significant at -60 dB (s11), however, the overall efficiency is 91%. The fact that the suggested antenna has good impedance matching, bandwidth, high gain, high return loss, radiation characteristics at the working band, and a compact and tiny size confirms that it is acceptable for use in 5G mm-wave applications.

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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
ε_r	Dielectric Constant

List of Abbreviations

RT	Duroid 5880
IEEE	Institute of Electrical and Electronic Engineers
LTE	Long Term Evolution
5G	Fifth Generation
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
FCC	Federal Communication Commission
SDR	Software Define Ratios
GSM	Global System for Mobile communication
3D	Three Dimension
2D	Two Dimension
VSWR	Voltage Standing Wave Ratio
WCC	Wireless Communication Centre
IE3D	Moment of Method-Based EM Simulator
HFSS	High-Frequency Structure Simulator
PCB	Printed Circuit Board

BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
MICs	Microwave integrated circuits
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System
FDMA	Frequency Division Multiple Access
FWA	Fixed Wireless Access

Chapter 1
Introduction

1.1 A Brief Antiquity of Wireless Communication

Radio is described as the transmission and receiving of electrical impulses or messages without the need for cables using electromagnetic waves. Radio waves are essentially electromagnetic radiation that travels through the air to a receiver. Wireless technology has a more than 200-year history. It started in 1747 when Benjamin Franklin demonstrated that electricity can travel through the air and offered an accurate model of electricity. Danish scientist Hans Christian Oersted noticed in 1819 that a compass needle will move in the presence of an electric field. This established the basic link between electricity and magnetism and led to the development of electromagnetics as a subject of study. Then, between 1865 and 1873, the Scottish scientist James Maxwell recognized the mathematical links between electricity and magnetism and developed four equations describing the propagation of electromagnetic waves across space. He demonstrated the fundamental concept of radio transmission by demonstrating that an oscillating electric field generates an oscillating magnetic field, which in turn generates an oscillating electric field in 1887, German scientist Heinrich Rudolf Hertz constructed the oscillator (an alternating-current generator) and is credited with the discovery of radio waves, marking the next stage in the evolution of wireless communications. Radio waves are fundamentally composed of two fields: electric and magnetic. These two fields are perpendicular to one another, and their total is known as the electromagnetic field. This constant flow of energy from one field to another is known as oscillation. Italian Guglielmo Marconi is credited with inventing the first radio transmitter in 1895. He transmitted the first radio telegraph message over the English Channel in 1895 and the Atlantic Ocean in 1901. Marconi filed a patent application for the world's first wireless telegraph utilizing Hertzian waves in 1896. In 1907, public radio was first used. Since the inception of radio communications, there have been two major concerns to solve, and they continue to be the primary objectives of the industry: increasing capacity and preserving quality.[56]

1.2 Radio-wave-based zero-generation technology (0G)

People were finally able to get their hands on wireless phones after the conclusion of World War II. The first generation of wireless phones was called 0G, which is also known as Zero Generation. During that time period, there were only a limited few communication channels that were available, and mobile carriers were the ones who were responsible for setting up the calls. There is a chance that not all mobile devices will be able to implement the handover techniques feature. This is a possibility. When moving from 0G to 1G to 2G to 3G to 4G to 5G, you will need to adjust the frequency of the channel. The mobile communication system that existed before the introduction of cellular technology in the early 1970s is referred to as "zero generation." For instance, prior to the development of mobile phones, some customers continued to communicate with one another using radio telephones while driving. The mobile radio telephony technology made it feasible for the modern cellular mobile telephone to mature into what it is today. Zero Generation Systems is the abbreviation for this category of systems, which is where the term "0G Systems" comes from. Considering the fact that they served as the foundation for the very first generation of mobile phones. Some of the technologies that were utilized in Zero Generation systems include Push to Talk (PTT), Mobile Telephone System (MTS), Improved Mobile Telephone Service (IMTS), Advanced Mobile Telephone System (AMTS), Norwegian Offending Land-Mobil Telephone (OLT), Public Land Mobile Telephony (PLT), and Swedish Mobile Telephony System D 15. (MTD). The technique was used by a wide variety of individuals, including but not limited to celebrities, construction managers, real estate salespeople, and loggers. The communication system only allowed for voice transmissions; hence voice communication was the only kind of communication it supported.[16]

1.3 Generation One Wireless Technology (1G)

The analog signal serves as the basis for the 1G standard, which is the first generation of wireless telephone technology. In 1980, when they were originally introduced to the market, these devices were first referred to as analog cell phones. In 1979, Nippon Telephone and Telegraph, better known as NTT, debuted the world's first completely functioning cellular system in the city of Tokyo, which was located in Japan. The Nordic Mobile Telephone (NMT) and the Total Access Communication System were the two analog technologies that had the most widespread adoption across Europe (TACS). During the 1980s, in addition to these two systems, another technology company also introduced analog systems in Europe. Despite this, the cellular network technologies were not able to interoperate with one another across countries, despite the fact that they did have handover and roaming capabilities.[15] The biggest drawback of first-generation mobile devices is that they can't communicate with each other across different countries. Not only is 1G's capacity low, but its handoff mechanism is erratic, and its voice communication is subpar. Calls were also vulnerable to eavesdropping since they were being played back in wireless towers, which were not equipped to prevent unauthorized parties from hearing them. In 1982, the AMPS protocol became the first 1G standard in the USA 3. The FCC has allocated 800–900 MHz of spectrum, with a 40 MHz channel width, for this system. In 1988, AMPS received 10 MHz of extra bandwidth, a feature known as "extended-spectrum" (ES).

Depending on the country's preferred method of communication, it went by several names: in Italy, it was RTMI; in France, it was Radio-Comm; and in the United Kingdom, it was 16 YACS. The first nations to adopt the new telecom standard known as C-450 were West Germany, Portugal, and South Africa. The First-Generation system, which includes mobile radio telephones and innovations such the AMTS, MTS, PTT, and IMTS, replaced the 0G system (IMTS).

- Began in the '80s and was finished in the '90s
- The Advance Mobile Phone System (AMPS) allows for data transfer speeds of up to 2.4 kbps.
- the first of its kind to be created and commercialized in the United States
- AMPS is widely regarded as the pioneering mobile phone system of its day.
- The user may only initiate a voice call from inside the same country. [15]

1.3.1 Important aspects of the 1G system's technology

Below are some of the primary 1G system features:

- 800 and 900 MHz in frequency
- ten megahertz (MHz) (666 duplex channels with a bandwidth of 30 kHz)
- Switching in analog technology
- Modulation: Modulation of Frequency (FM)
- Voice-only service mode
- Frequency Division Multiple Access is a method of access (FDMA)

1.3.2 Drawbacks of the 1G system

The following list of the 1G system's drawbacks

- Poor battery life;
- large mobile phone size that makes it difficult to carry;
- decreased safety (calls could be intercepted using an FM demodulator);
- Voice quality as a result of weak interference
- few users and insufficient cell coverage.
- It was impossible to roam between similar systems. [11]

1.4 Wireless Technology of the Second Generation (2G)

The Second-Generation wireless network, or 2G, was developed using 1990s-era digital technologies. In 1991, 2G was launched in Finland. It offered services like the Multimedia Message System (MMS), SMS, and photo messages (MMS). Similar to 2G, digital encoding is used to digitally encode text messages and audio signals, enabling data to be transferred in a way that only the specified receiver can receive and decode the data. Greater security is offered by 2G for both transmitter and receiver. In 2G, CODEC (compression-decompression algorithm) is utilized to compress and multiplex digital signals. In the 2G system, digital multiple access was implemented using TDMA and CDMA. TDMA divides the signal into time slots, whereas CDMA assigns a unique communication code to each user in a multiplexed manner. The Digital Enhanced Cordless Telecommunications (DECT) standard for portable mobile phones uses TDMA technology along with the Global System for Mobile Communications (GSM), Personal Digital Cellular (PDC), IS-136, and iDEN standards. The first 2G system was GSM. It is the most widely used mobile standard among all wireless mobile device technologies used in 212 nations throughout the world. GSM technology, which enables consumers to use their mobile phones in numerous countries, was the first to establish international roaming between various mobile phone operators.

Up to 8 calls per channel can be multiplexed in GSM using TDMA technology in the 900 MHz and 1800 MHz frequency bands. It transmits circuit-switched data and speech signals at a rate of up to 14.4 kbps. A fresh spectrum block in the US 1900 MHz band was also put up for sale by the FCC. A variety of new technologies have been created on the foundation of the original GSM, prominent in some advanced systems, defined as 2.5 generation (2.5 G) systems, over the past 20 years to deliver improved services.[15]

1.4.1 Key characteristics of the 2G system

Key characteristics of the 1G system are as follows:

- SMS services are available
- Digital system (switching).
- Enhanced security
- encrypted audio communication
- The first internet with a lower data rate is all possibilities.
- The 2G system has drawbacks like low data rates Restricted mobility
- Fewer functions for mobile devices.

- Hardware limitations in terms of users and capabilities. [11]

1.5 GPRS (General Packet Radio Service) 2.5G

A mobile wireless standard known as 2.5G, which stands for "second and a half generation," was created in the interim between its predecessor, the second generation, and its successor, the third generation. The "General Packet Radio Services" are referred to as being "second and a half generation." The data rate offered by GPRS ranges from peaking at 56 Kbit/s to peaking at 115 Kbit/s. It supports features including Wireless Application Protocol (WAP), Access Multimedia Messaging Services (AMMS), and internet features like email and World Wide Web (WWW) access. In contrast to how conventional Circuit switching charges for data communication, GPRS charges for data transfer in terms of traffic megabytes transmitted [15]

1.6 Wireless Technology of the Third Generation (3G)

The third generation of wireless communication standards, superseding 2.5G and coming before 4G, is defined by the Telecommunications Standards Group (3G). The International Telecommunication Union (ITU) developed a strategy to make use of the 2000 MHz global frequency band, which will be able to support a single, universal wireless network standard. "International Mobile Telephone 2000" or "IMT-2000 Standard" is the name of the program. There are three different kinds of multi-access technologies. CDMA 2000 is one of them and was developed based on Code Division Multiple Access Technology by the North American Wireless Telecommunications Standards Group. It has a 1.25 MHz channel width and speeds of up to 144 Kbps.

WCDMA (UMTS): In 2001, NTT Do Como introduced the first commercial WCDMA FOMA service in the world in Japan. Wide Band Code is being developed as a Multiple Access Division. It has a 5 MHz channel width and speeds of up to 2 Mbps. The Time Division Synchronous Code Division Multiple Access (TD-SCDMA) technology was proposed by the China Wireless Telecommunication Standards Group for use in 3G. [15]

In order to continue that effort, the Third Generation Partnership Project (3GPP) developed a wireless system that meets the requirements of the IMT-2000 standards. In the year 2000, the third generation, or 3G, of wireless technology entered commercial use.

The peak data transfer speed supported by earlier technology was 144 Kbps, however, 3G has upped it to 2 Mbps. To use 3G services, a smart phone or multimedia mobile phone is necessary. 3G now offers greater bandwidth and data transmission rates to support web-based apps, audio, and video files.

With the use of 3G technology, network operators are able to provide their users with a wider range of more advanced amenities by improving network capacity and Spectral Efficacy. Wide-area wireless phone calls, video calls, mobile television, wireless broadband data, GPS service, and video conferencing are all included in the 3G system services, which are all provided in a portable wireless environment. This network has advantages over the 2.5G network as earlier described below [16]:

1. Significantly faster data transfer rate.
2. Enhancements to audio and video streaming
3. A facility for video conferencing
4. Quicker browsing on the Web and WAP
5. Support for IPTV (TV via the Internet)

1.6.1 Important facets of the 3G network

The 3G system's salient characteristics are as follows:

- Higher data rate
- Video calling
- More users, more coverage, and enhanced security
- Aid with multimedia communications
- Support for mobile apps
- Maps and location tracking
- Enhanced TV streaming, enhanced online surfing
- Superior 3D gaming [11]

1.6.2 3G technology's shortcomings

The list of disadvantages to the G system is as follows-

- In no particular order: expensive licensing for the spectrum
- Expensive equipment, infrastructure, and implementation
- A need for more bandwidth to permit larger data rates
- High-end mobile devices
- Interoperability with earlier 2G systems and frequency bands [11]

1.7 Wireless Technology of the Fourth Generation (4G)

In order to provide high-speed data transfer rates, such as 100 Mbps as the peak data rate for both the server and the receiver of data, who are moving at a speed of 60 km/h, interoperability between various categories of networks is the basic idea behind 4G. When the server and receiver are stationary, the data transfer rate should not exceed 1 Gbps; [15]. Figure 1.3 compares several generations of 4G smartphones. Fourth-generation (4G) mobile network standards are currently being used, and in many nations, they have supplanted third-generation (8 networks). In a separate setting, scholarly research on 4G is just the beginning. Having issues being deployed and meeting the throughput and performance requirements. With the use of numerous technologies, including Wi-Max, Wi-Fi, EDGE, WAP, GPRS, and Wi-Bro in 3G, we can now access the internet using our mobile devices. However, users run into problems when they have to travel to locations where interoperability between various networks is achieved because they are stuck when they have to deal with the restrictions and challenges of 3G while using any of the aforementioned technologies to access the internet through a cell phone. Users of 4G can connect to the network using any of the aforementioned technologies even when they move from one location to another. The following problems are believed to have been resolved with the 4G network:

1. In order to increase security, 4G wireless technology added an IP capability to the mobile phone due to high data transfer speeds.
2. With the fourth-generation wireless standard, users can access mobile devices at a data rate of 100 Mbps and stationary devices at a rate of 1Gbps for local mobile network connectivity.
3. A new technology called OFDMA was introduced in 4G to replace Hybrid-based technology, which was used in 3G and combined CDMA and IS-95.
4. Compared to earlier TDMA or CDMA, OFDMA is more effective.
5. An outstanding feature of fourth-generation wireless systems is the use of OFDMA, in which data are conveyed by allotting the channel into a small band for increased efficiency.
6. 4G will be referred to as Wireless Mobile Broadband Access (WMBA), which is where IEEE 802.16e processing is located. This shows that the internet is accessible. The execution is being developed in order to prevent call interruptions when downloading data from any website. The proposal of a downlink data rate of 128 Mbps and an uplink data rate of 56 Mbps is an extraordinary advancement in 4G wireless technology. The service's restriction is that Internet connectivity depends on the presence of a hotspot.
7. LTE, a wireless system for internet access, is expected to be included in 4G mobile phones concurrently with Worldwide Interoperability for Microwave Access (WiMAX). There is a comparison between WiMAX and LTE in the center. LTE stands for Internet Protocol Address and follows the TCP/IP concept derived from the computer networking architecture. Greater safety, high data transferability, low latency, and the ability to manage bandwidth will all be provided. In order to backup data across the two networks, 4G or LTE is also compatible with CDMA technology.
8. The two main wireless technologies that the 3GPP will introduce are LTE and IEEE 802.16m. A portion of the fourth-generation wireless system has already been granted approval for additional processing. As of June 2009, IPv6 is allowed as a 4G wireless standard by default. [15]

1.7.1 Important aspects of 4G systems

The following list contains 4G system highlights.

- Significantly higher data rates of up to 1Gbps
- Improved security and mobility
- Mission-critical applications with less delay
- High-definition video streaming and games
- Voice over LTE network (using Voice IP Packets)

1.7.2 Negative aspects of the 4G system

Below are several 4G system drawbacks.

- Expensive hardware and infrastructure
- Exorbitant spectrum (in most countries, the frequency bands are too costly.)
- It requires pricey, high-end mobile handsets that are compatible with 4G technology.
- Large deployments and upgrades take time. [11]

1.8 Wireless Technology of the Fifth Generation (5G)

The deployment of the fifth generation, or 5G, of wireless technology standards, is anticipated to begin around 2020. By providing improved bandwidth, high data transfer rates, and decreased latency to a billion electronic devices, 5G will enable wireless networks. This is one of the technological concerns that has received the most attention and promises to make self-driving cars, virtual reality (VR), and the Internet of Things more accessible (IoT). A formal standard or official document for 5G has not yet been finalized by telecommunications companies or regulatory authorities like 3GPP, WiMAX, or ITU-R.

The wireless level of excellence communication systems in cell phone wireless technologies are said to be 5G technology. Today, wired connectivity is all but obsolete. Cell phones are currently being utilized for a number of other purposes in addition to serving as a communication tool. The simplicity of exchanging phones and data is facilitated by older wireless technology; however, the fifth generation is bringing in a new level and transforming human life into a truly mobile life.

1.8.1 5G's features

The feature of 5G is listed below: 1–10Gbps connections to field end points.

- 1000x bandwidth per unit area
- 1 MS latency.
- 10 to 100 times as many connected devices.
- 99.999 percent availability
- 100% coverage
- 90% reduction in system energy use [11]

Generation	Speed	Technology	Time period	Features
1G	14.4 Kbps	AMPS, TACS, NMT	1970 from 1980	During the 1G time period, mobile communicators are exclusively utilized for voice communication.

2G	9.6/ 14.4 Kbps	CDMA and TDMA	1990 from 2000	Time division allows for the connection of a number of users to a specific channel, which enables the achievement of 2G capabilities. During the 2G network, mobile phones and speech are also utilized to send and receive data
2.5G	171.2 Kbps, 20-40 Kbps	GPRS	2001 from 2004	The number of people using the Internet is growing, and an increased emphasis is being placed on having a good education. The availability of multimedia and streaming services is starting to grow. Cell phones have recently started to offer web surfing, albeit only a limited number of mobile phones now have this capability.
3G	3.1 Mbps, 500-700 Kbps	EDGE, CDMA-200 UMTS	2004 from 2005	Broadcasting video and audio are both supported. Mobility and global connection are enabled through a broad range of types (cell phones, personal digital assistants, etc
3.5G	14.4 Mbps, 1-3 Mbps	HSPA	2006 from 2010	To support speed data, it provides higher throughput and speeds.
4G	100-300 Mbps. 3-5 Mbps 100 Mbps (Wi-Fi)	LTE, WiMax, Wi-Fi	Now (Read more about the transition to 4G)	To meet the growing demand for data access across a variety of service providers, 4G speeds continue to increase. Broadcasting in high fidelity is also possible over a 4G connection. New phones featuring full high-definition user interfaces. Quite a chill is setting in. The 4G upgrade considerably enhances mobility. It's not unthinkable to travel the globe.
5G	2-20 Gbps	Beam forming, Massive MIMO, mm wave	2022	The most recent technological advancement is known as 5G. Customers will have access to very fast speeds when this is finally made accessible to them. Additionally, it will make efficient use of the available bandwidth.

TABLE 1.1 GENERATION OF COMMUNICATION [15]

This section will conclude with a brief overview of current wireless systems in the following table, as well as the forthcoming generation of wireless networking technologies. These new technologies will be wonderful and have a long way to go in the next few years. Features will eventually roll [13] Table 1.1 displays the production of communication.

1.9 The revolution of Wireless Communication

To accommodate rising demand and more stringent specifications, wireless technology has been advancing rapidly. Since the rollout of first-generation mobile networks, the telecoms sector has encountered numerous new hurdles in terms of technology, effective spectrum utilization, and, most significantly, security for end users. Future wireless technologies will deliver mobile networks that are extremely fast, packed with features, and highly secure.[11]

1.10 Update on 5G spectrum globally

These bands have been designated or chosen as targets throughout the world.

The electromagnetic spectrum, and more specifically the radio spectrum, is used by 5G to transmit data wirelessly. There are several different levels of frequency bands contained within the radio spectrum; some of these bands are utilized for this next-gen technology. You might have heard about the 5G bandwidth spectrum, spectrum auctions, mm-Wave 5G, and other similar topics, despite the fact that the deployment of 5G is still in its early phases and is not yet available in all countries.

It is okay if you find this to be unclear. The only thing about 5G frequency bands that are truly important for you to understand is that various companies transmit data using various parts of the spectrum. The choice of which part of the spectrum to utilize has an effect, not only on the speed of the connection but also on the distance it may go. There will be much more on this below.

The frequencies of radio waves can range anywhere from three kilohertz (kHz) all the way up to three hundred gigahertz (GHz). Every part of the electromagnetic spectrum can be broken down into distinct frequency ranges that are referred to collectively as bands.

Radio spectrum bands include those with extremely low frequency (ELF), ultra-low frequency (ULF), low frequency (LF), medium frequency (MF), extremely high frequency (UHF), and extremely high frequency. Other bands include extremely high frequency (EHF), ultra-high frequency (UHF), and extremely high frequency (EHF).

Many people refer to the portion of the radio spectrum that has a high-frequency range between 30 GHz and 300 GHz as the millimeter band. This portion of the electromagnetic high-frequency band (EHF band) (because its wavelengths range from 1-10 mm). Therefore, the wavelengths that fall within and near this band are referred to as millimeter waves (mm Waves). Mm-Waves are a popular option for 5G, but they can also be used in fields like radio astronomy, telecommunications, and radar weaponry.

UHF, which is located lower on the electromagnetic spectrum than EHF, is yet another portion of the radio spectrum that is being utilized for 5G. The UHF band encompasses a frequency range of 300 MHz to 3 GHz and is utilized for a wide variety of applications, including TV transmission, GPS, wireless Internet, cordless telephones, and Bluetooth.

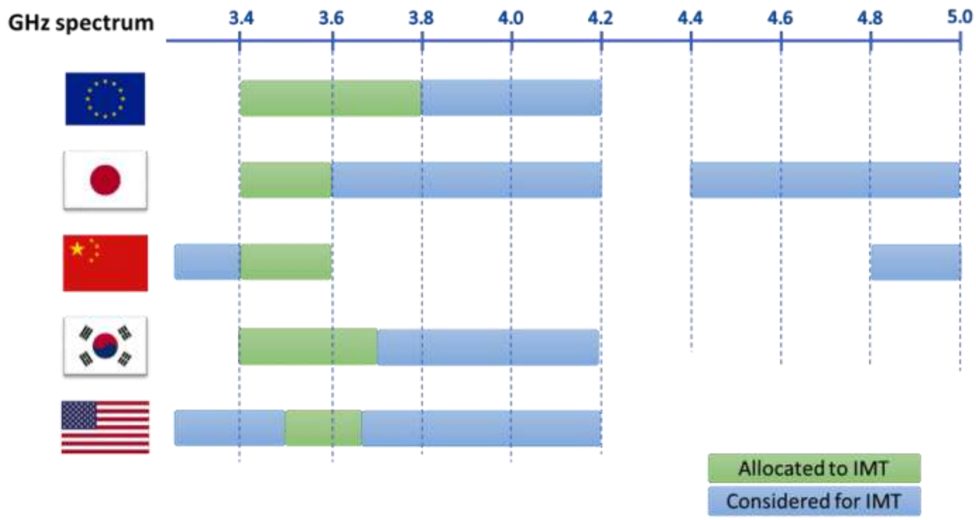

Figure 1-0-1 Worldwide 5G spectrum allocations

1.10.1 In order to make 5G possible, the FCC is driving key spectrum initiatives.
Including mmWave, in addition to low-band, mid-band, and high-band frequencies

Figure 1-2 5G Band

1.10.2 Low-band
Public auction of the Broadcast Incentive

1. After the assignment phase, a portion of the 600 MHz band that had been up for auction was successful enough to generate profits of $19.8 billion.
2. 70 MHz of licensed spectrum that is split into two distinct channels and
3. additional use of 14 MHz for unlicensed communication.

4. The frequency and timing of spectrum use are compatible with 5G [16]

1.10.3 Mid Band

Residential Broadband Radio Services

1. Establishing a bandwidth of 150 MHz for PAL1 and GAA2 and performing a band-3-layer swap with the existing users of 3.5 GHz.
2. In 2017, the FCC developed PAL directions with the intention of making them suitable for 5G.
3. The CBRS Alliance was formally presented in an effort to establish an ecosystem based on LTE.
4. The FCC has informed those inquiring about the 3.7-4.2 GHz and 5.9-7.1 GHz bands. [16-17]

1.10.4 High-band

A Decision Will Be Made Regarding Spectrum Frontiers in 2016 and 2017 The Second Judgment

1. It frees up approximately 11 GHz in a number of mm-wave bands.
2. Seventy percent of recently released bands either do not have licenses or share their music.
3. Consistently shared the same opinion. The FCC has requested observations on a different candidate spectrum that has been branded for IMT-2020.
4. Taking into consideration the addition of frequency ranges of 24.25-24.45, 24.75-25.25, and 42-42.5 GHz. [16-17]

1.10.5 High-band: Spectrum Frontiers, the governing body for 5G mm-Wave bands

The spectrum that is both shared and unlicensed is essential to the creation of more bandwidth.

Spectrum That Is Under License

1. 27.5 GHz – 28.35 GHz

2. 37.6 GHz – 38.6 GHz

3. 38.6 GHz - 40 GHz

spectrum that is both licensed and unlicensed for use

1. 37 GHz– 37.6 GHz

2. 64 GHz- 71 GHz [16-17]

1.10.6 5G Spectrum in Europe

Focus on the middle band between 3.4 and 3.8 GHz, as well as the 26 GHz band (24.25-27.5 GHz) The EC RSC, CEPT, and key European Member States are driving the regulatory activities that are being done in the EU in order to speed up the rollout of 5G**.**

- Supervisory the 3.4-3.8 GHz events, as well as 26 GHz, will run extremely predictably for auctions in 2017-2018.
- In March 2017, the government of the United Kingdom published its approach to 5G.
- In the frequency range of 3.4 GHz to 3.6 GHz, Ofcom intended to hold an auction for 150 MHz of channel space in 2017 and 2018, followed by an auction for 110 MHz of channel space in 2018 and 2019.
- Ofcom has introduced a work platform on the availability of the 26 GHz band in order to facilitate the timely organization of 5G.
- In 2018, the Italian government is planning to hold auctions for the frequencies 700 MHz, 3.6 GHz–3.8 GHz, and 26 GHz–27.5 GHz.
- The government of Ireland was successful in its effort to auction off 350 MHz of frequency spectrum for 5G communication.
- In 2018, the government of Spain issued permits for the 3.6 GHz-3.8 GHz band in response to market demands and the needs of operators.
- Spain, with a particular emphasis on the 26 GHz band. At least 1.4 gigahertz of available bandwidth will be used for the release in 2018.
- Other countries, such as Belgium, Austria, and Switzerland, are making preparations to be free during the time frame of 2018-2019. [16-17]

1.11 Antenna Basics

An antenna is a specialized transducer that converts radio-frequency (RF) fields into electrical energy or vice versa. Antennas are used in wireless communication. There are two primary varieties: the receiving antenna, which gathers radio frequency (RF) energy and supplies alternating current to the apparatus, and the transmitting antenna, which is fueled by the apparatus's electrical energy and generates radio-frequency fields. The receiving antenna is the more common of the two. The microstrip patch antenna is the most common type of antenna that is used for wireless communications and is the most common type of antenna used in wireless applications. In most cases, microwave frequencies are the only sensible operating range for microstrip patch antennas.[3]

1.11.1 Frequency

When used in its traditional sense, the word "frequency" refers to the number of times a specific event occurs during a given time period. In its most basic form, the frequency can be defined as the number of occurrences of an event within a specific period of time. According to the standard definition, frequency is "the number of recurrences of a signal over a defined time period (1 second)." A time period is the amount of time that passes between each repetition of a periodic signal, denoted by "T." The frequency of a periodic signal is simply the time period's opposite in sign and magnitude (T). The rate at which oscillatory and vibratory events take place is referred to as frequency in engineering jargon. Some examples of oscillatory and vibratory events include radio waves, audio signals (sound), mechanical vibrations, and light. Hertz is the name given to the unit of frequency in the International System of Units (SI) that was named after the German physicist Heinrich Hertz (Hz). A signal or event is said to have a frequency of one hertz if it occurs once every second.[5]

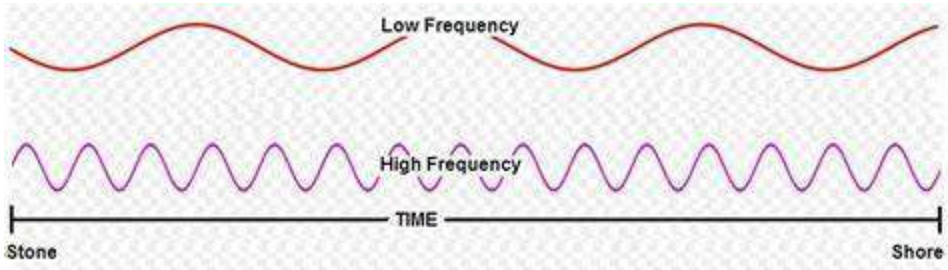

Figure 1-0-2 High frequency and Low frequency diagram

1.11.2 Bandwidth

Bandwidth is the capacity of a wired or wireless communications system link to transmit the maximum amount of data from one point to another over a computer network or internet connection in a given amount of time, typically in one second. Bandwidth is defined as the capacity of a wired or wireless communications system link to transmit the maximum amount of data. When discussing antennas, the term "bandwidth" refers to the frequency range that falls within the scope of the antenna's ability to radiate or receive energy effectively. When selecting an antenna, bandwidth is consistently regarded as one of the most important and desirable determining parameters. For instance, the bandwidth of many different types of antennas is extremely limited, so they cannot be used for wideband operation.[8]

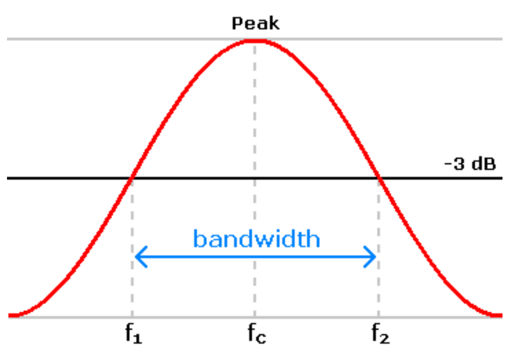

Figure 1-0-3 Bandwidth Diagram

1.11.3 Input Impedance

The ratio of the voltage to the current at the input terminals of an antenna is the definition of what is known as the antenna's input impedance. An important parameter of an antenna, resonance frequency is a parameter that expresses the antenna. The input impedance is composed of real and imaginary components in equal measure. The real part of the input impedance is a representation of the power that is either radiated away from the antenna or absorbed by the antenna itself. The power that is stored in the near field of the antenna is known as reflected power, and it is represented by the imaginary part of the input impedance. An antenna is considered to be resonant when its real input impedance is equal to or less than its imaginary impedance. The length and size of an antenna are the two primary factors that decide the input impedance of that antenna. Z is the symbol for impedance, and it has both a true portion, which consists of the radiation resistance of the antenna denoted as Road and its ohmic losses denoted as R ohm, and a reactive portion X[21].

1.11.4 Impedance Matching

Impedance matching is described as "the approximate impedance value of the transmitter being equal to the approximate impedance value of the receiver, or vice versa," as stated in the standard definition of the term. When it comes to wireless communication, it is essential to have impedance matching between the antenna and the circuitry. The term "tuning" or "matching" the antenna comes from the theory of Maximum Power Transfer, in which adjusting the impedance of the antenna, the transmission line, and the circuitry across a frequency range is referred to as "tuning" the antenna.

The value of the voltage standing wave ratio (VSWR) is used to characterize the quality of the match, and bandwidth is the frequency range over which the antenna impedance is relatively close to 50 ohms for a given VSWR. A device is said to be resonant if it has the ability to produce better output within a specific frequency band.

Resonant devices, such as antennas, have impedances that, when matched, resulting in improved signal output.

The importance of impedance matching will be discussed further below.

1. The power from the source will be effectively delivered to the feedline if the impedance of the feedline is the same as the impedance of the source.
2. If the impedance of the antenna is the same as that of the feedline, then the power from the feedline will be effectively transferred to the antenna.
3. The output impedance of the receiver antenna should be the same as the input impedance of the circuit that makes up the receiver amplifier.
4. The input impedance of the transmitter antenna ought to coincide with both the output impedance of the transmitter amplifier and the impedance of the transmission line.[10]

1.11.5 Directivity and Gain

Directivity is the ability of an antenna to either radiate energy in a specific direction when it is transmitting energy or to receive better energy from a specific direction when it is receiving energy. And gain is generally defined as the ratio of the power generated by the antenna from a far-field source on the beam axis of the antenna to the power generated by a hypothetical lossless isotropic antenna that is equally sensitive to all directions of signals. This is done to compare the power generated by the antenna to the power generated by the hypothetical antenna. Gain and directivity are related to one another in some fashion. This connection is made clear by observing an effect known as increased directivity, which occurs when contrasting a light bulb with a spotlight. In some directions, a spotlight with 100 watts of power can produce more light than a light bulb of the same wattage, while in other directions, it can produce less light. Comparing the light bulb to the spotlight, one could say that the light bulb has less "directivity." The spotlight is located in close proximity to an antenna with a high degree of directivity. Gain is the operational benefit that comes from being direct. In terms of mathematics, the gain is equal to the product of a system's directivity and efficiency. The relation between gain and directivity includes a newly introduced parameter denoted by the symbol (). This parameter is referred to as the efficiency of the antenna.[18]

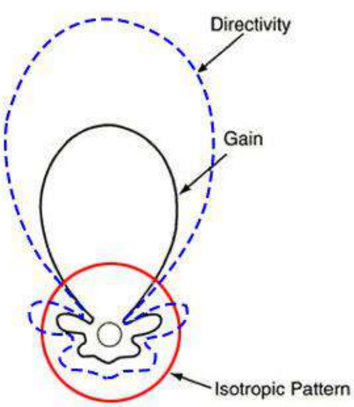

Figure 1-0-4 Directivity and Gain

1.11.6 Distribution of Radiation

In the field of antenna design, the directional (angular) dependence of the frequency of the radio waves emitted by the antenna is referred to as the radiation pattern. This term is also known as the antenna pattern or the long field pattern. The relative strength of the radiated field at a constant distance away from the antenna and in each of the different directions is what the term "radiation pattern" refers to. Due to the fact that it also defines the antenna's receptor properties, the pattern of radiation is also referred to as a "reception pattern." It is difficult to display the three-dimensional pattern of radiation in a way that is true to life due to the fact that the pattern of radiation itself is three-dimensional.

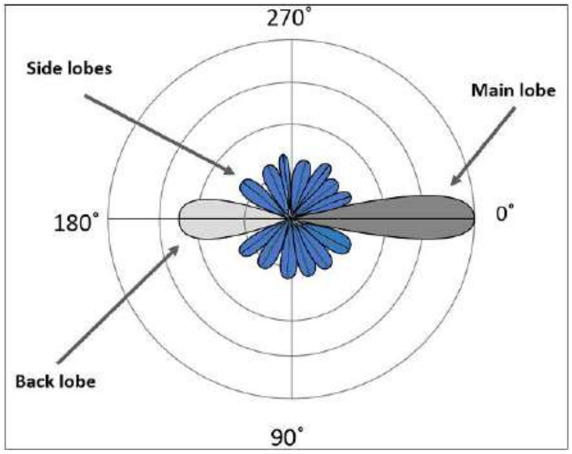

Figure 1-0-5 Radiation pattern

Figure 1.6 illustrates the pattern that the radiation creates. It is frequently a time-consuming process to measure the three-dimensional radiation pattern.

The radiation patterns that are calculated are typically a section taken from a three-dimensional pattern. This results in a radiation pattern that is two-dimensional and can be easily viewed in a two-dimensional format on a computer or paper. These types of measurements can be displayed in either a rectangular or a polar format. [17]

1.11.7 Voltage Standing Wave Ratio (VSWR)

VSWR (Voltage Standing Wave Ratio) is a calculation of how radio-frequency power is transmitted effectively from a power source through a load via a transmission line. In other words, the ratio of maximum power to minimum wave power can be calculated and the standing wave ratio is called (SWR). In terms of voltage, the ratio of the reflected voltage over the incident voltage is called VSWR. The VSWR is always an antenna number that is true and positive. The lower the VSWR is, the more the transmission line is matched to the antenna and the more power is supplied to the antenna. In this case, no power is reflected from the antenna, which is the perfect case [17]. The minimum VSWR is 1 The VSWR is shown in Figure 1.7.

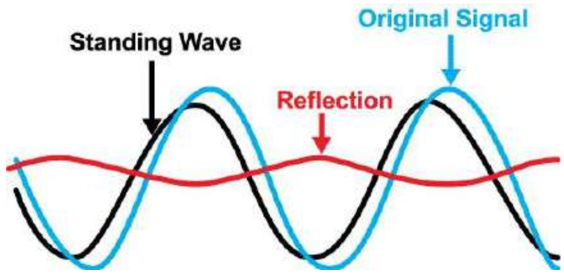

Figure 1-0-6 VSWR

1.11.8 Return Loss (RL)

The percentage of radio waves that are rejected by an antenna when they arrive at its input is measured by a statistic called the Return Loss. This loss is expressed as a ratio and is compared to the number of radio waves that are accepted. The value is given in decibels (dB) when discussing a short circuit (100 percent rejection). Return loss is an additional method that can be used to express the mismatch between the antenna and the feedline (RL). The algorithmic ratio compares the power that is reflected by the antenna to the power that is fed into the antenna from the transmission line. This comparison is done in decibels (dB). There is a one-to-one relationship between the RL and the VSWR. In actuality, the parameter S11 is the one that is mentioned in relation to antennas the most frequently. In reality, all that constitutes S11 is the return loss (RL). If S11 is equal to 0 dB, then nothing is radiated and the antenna is responsible for reflecting all of the powers. If S11 is equal to -6 dB, this indicates that the reflected power is equal to -3 dB when the power that is delivered to the antenna is 3 dB. A VSWR that is less than or equal to 2 is considered to be acceptable. This number corresponds to an RL or S11 that is -9.5 dB or lower. According to this thesis, an RL of -10 dB is considered to be satisfactory [21].

1.11.9 Polarization

The polarization of the antenna is established by the electrical wave field that is generated by the antenna itself. To be more specific, the magnitude and phase of the electric field are what determine the polarization of the antenna. The antenna is said to have linear polarization when both the magnitudes and phases of the various components of the electrical field are identical. When the magnitudes of the two components are the same, but the phases differ by 90 degrees, the antenna is said to be circularly polarized. In order for two linearly polarized antennas to interact with one another, it is necessary for the electrical fields that are predicted by each of them to be aligned. However, a circularly polarized antenna is able to interact with any linear antenna regardless of the orientation of either of the two antennas. In contrast to a circular antenna, which is unaffected by the direction in which it is positioned, a linear antenna directs all of its power in a single path rather than dividing it between the two components, which allows it to radiate more power.

There are positive aspects to each and every type of polarization. Depending on the use, the reader antenna can take the form of a linear or circular configuration.

It is recommended that the antenna of the tag be circularly polarized so that it can be read from any angle [12]. The three different kinds of polarization are depicted in figure 1.8.

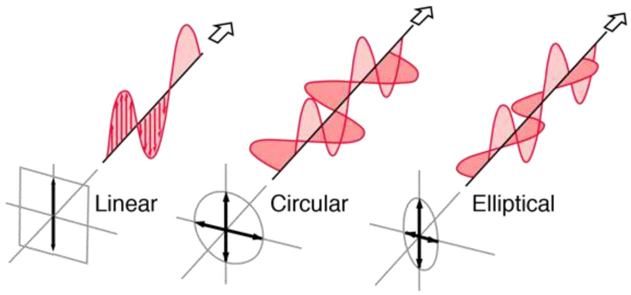

Figure 1-0-7 Polarization Linear, Circular, Elliptical

1.12 Microstrip Antenna

As can be seen in Figure 1.9, a microstrip patch antenna is made up of a radiating patch that is placed on one side of a dielectric substrate, and the other side of the substrate contains a ground plane. The patch is typically constructed out of a conductive material such as copper or gold, and it can take on the form of anything imaginable. In most cases, the radiating patch and the feed lines are engraved using a photo machine onto the dielectric substrate.

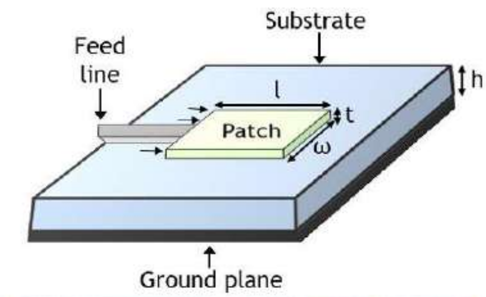

Figure 1-0-8 A Microstrip Patch Antenna Arrangement

In order to simplify the analysis and the performance forecast, the patch is typically square, rectangular, circular, triangular, elliptical, or another typical shape. In the case of a rectangular patch, the length of the patch, denoted by the symbol L, is typically calculated as 0.3333 0L 0.55-0070, where 5.007 refers to the wavelength in free space. The size of the patch was deliberated upon, and as a result, it is t=0 (where its the patch thickness). The height h of the dielectric substrate is typically in the range of 0.0035-007-0. h 0.055-0070. In most cases, the substrate dielectric constant, denoted by sr, falls somewhere in the range of 2.2 to 12 Microstrip patch antennas are characterized by primary radiation due to the presence of fringing fields between the patch edge and the ground plane. If you want your antenna to have good performance, you should look for one that has a thick dielectric substrate with a low dielectric constant. This will give you better efficiency, a higher bandwidth, and better radiation. This design, on the other hand, contributes to a larger overall size of the antenna. When building a compact Microstrip patch antenna, it is necessary to use dielectric constants that are higher, which makes the antenna less effective and results in a narrower bandwidth.

1.12.1 Microstrip antenna Feed Techniques

- The Microstrip Line Feed System
- Feeding via Coaxial or Probe
- The Aperture Coupled Feed System
- the Proximity Coupled Feed system

1.12.2 Feeding of the Microstrip Lines

In this form of feeding, the microstrip transmission line is etched directly on the edge of the patch. As a result, the entire structure is maintained on the same plane. The microstrip feed line is shown in figure 1.9.

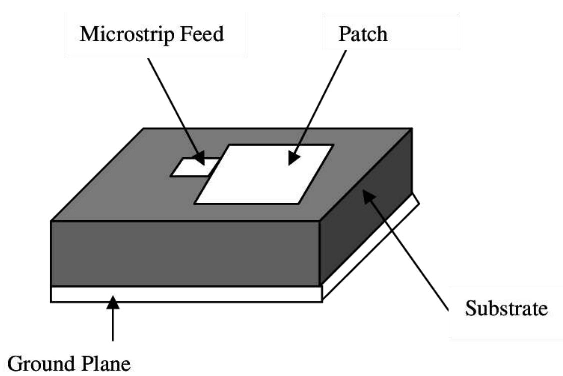

Figure 1-0-9 Microstrip Line Feeding

1.12.3 Feeding via Coaxial Cable or Probe

The ground plane is attached to the outer conductor of the coaxial connector, while the inner conductor of the coaxial connector travels through the substrate and is welded to the radiating patch. Figure 1.10 depicts a coaxial feeding configuration.

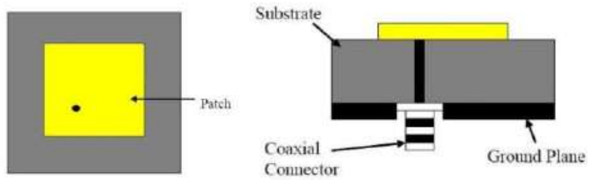

Figure 1-0-10 Coaxial / Probe feeding

1.12.4 Coupled Aperture Feed Input

Within this form of feed, the opening coupling is made up of two substrates that are kept apart from one another by a ground plane. The radiating patch and the microstrip line are separated by the ground plane, which is located at the bottom of the lower substrate. A slot cut or an electrically small aperture is used in the ground plane to accomplish the coupling. The aperture-coupled feed is depicted in figure 1.12.

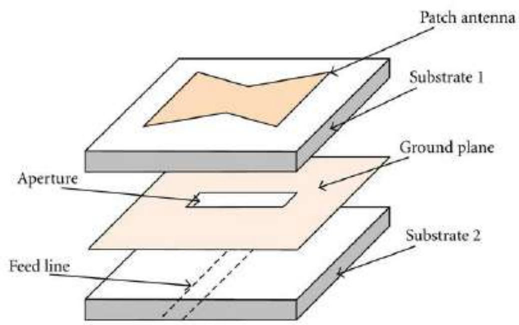

Figure 1-0-11 Aperture-Coupled Feed

1.12.5 Feed for Proximity Coupled Receivers

Electromagnetically Coupled ECMSA is another name for this phenomenon. Additionally, it is made up of two different substrates. The microstrip's feed line can be found between the two substrates, and the radiating patch can be found on the uppermost layer of the uppermost substrate.

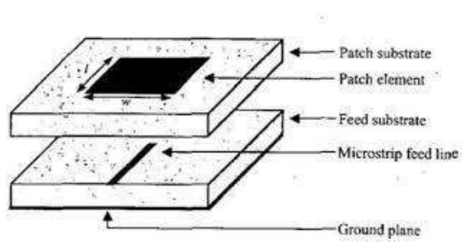

Figure 0-12 Proximity-Coupled Feed

1.12.6 The Benefits and Drawbacks of Using a Microstrip Antenna

Microstrip patch antennas are gaining popularity for use in wireless applications due to their low-profile construction, which contributes to the growth in popularity of this type of antenna. Additionally, they are highly compatible with the antennas that are embedded in wireless handheld devices such as mobile phones, pagers, and other similar devices. When it comes to missiles, the telemetry and contact antennas need to be patch antennas for microstrips that are also very small and conformal.

The following is a list of some of the benefits that come with using a microstrip antenna:

1. Microstrip antennas are characterized by their low volume and light weight.
2. They are capable of being produced at a low cost, and as a result, they are able to be manufactured in large quantities.
3. They have a configuration that is low-profile and planar, and they are easily adaptable to the surface of the host.
4. Designed to work with both linear and circular polarizations simultaneously.
5. Microstrip antennas are easily compatible with integrated microwave circuits and can be integrated with them (MICs).
6. They are able to perform operations at dual and even triple frequencies.
7. When mounted on rigid surfaces, they have a high level of mechanical durability.

The following is a list of some of the drawbacks of using a microstrip antenna:

1. The bandwidth of a microstrip antenna is quite limited.
2. They have a poor rate of productivity.
3. The benefits they provide are minimal.
4. They are negatively affected by the external radiation that comes from the feeds and junctions.
5. Unsatisfactory end-fire radiator, with the exception of tapered slot antennas
6. They have a limited capability of dealing with power.
7. The excitement caused by surface waves

There is an antenna available that is of very high quality for microstrip patch antennas (Q). A high Q reflects losses associated with the antenna, and a high Q contributes to bandwidth and performance that are both low.

It is possible to achieve a lower value for Q by growing the thickness of the dielectric substrate. As the thickness of the layer increases, however, the amount of power that is transferred into the surface wave from the source rises to an increasing proportion. This contribution of the surface wave can be counted as an undesirable loss of power because it causes the characteristics of the antenna to deteriorate as it is gradually distributed in the dielectric bends. This happens because it causes a loss of power. [22].

1.13,1 To what end does 5G mmWave exist?

High-end innovations, including driverless cars, rely on the bandwidth and latency improvements made feasible by 5G mmWave. In situations calling for ultra-low latency and greater speeds over shorter distances, MmWave shines. Technologies like autonomous cars rely on receiving inputs and processing data in near real-time, thus this kind of communication is essential. To avoid traffic and potential accidents, autonomous cars may utilize the 5G mmWave frequency to communicate with other vehicles on the road. With the prior cellular standards, this kind of real-time communication was very unlikely. 5G mmWave offers some of the fastest speeds available today, making it ideal for situations where milliseconds count.[57]

1.13.2 mmWave 5G's Advantages

5G mmWave networks will be useful for both consumers and enterprises. Small cells might be used by some companies to bring 5G mmWave signals from carrier networks inside their buildings, while others may choose to use just cell towers outside. In most cases, small cells are the best choice because high-frequency mmWave operation has a shorter range (when compared to the traditional low and mid-band frequencies used by cellular wireless) and cannot provide reliable coverage indoors because of the presence of obstacles like walls and ceilings. The difficulty of providing service inside with mmWave cell towers located outside rises as energy-efficient building materials become the norm. In general, 5G mmWave will provide the following advantages for both consumers and businesses:[58]

- the very maximum in 5G speed, including quicker downloads and data transfers.
- Extremely focused cellular coverage, perfect for congested areas and corporate uses
- These ultra-fast connections fuel augmented reality, crisis management, driverless cars, and other cutting-edge technologies.
- Extending the range of a company's tiny cells lets them provide more mmWave service.
- The Applications of 5G Millimeter Wave Technology
- Despite the novelty of mmWave technology, several companies are already planning to integrate it into their infrastructure. Here are some current instances of businesses making use of 5G mmWave to advance their offerings.[59]

1.13.3 "Smart" Cities

Although the concept of "smart cities" may seem futuristic, it is very present. Large metropolitan regions are already making use of 5G networks to improve garbage collection, public transportation, and even crime mapping in real-time. For example, high-definition live security camera feeds may be supported in automobiles through internet backhaul thanks to the 5G mmWave band's widespread availability in smart cities.[57]

1.13.4 Business applications

Companies may now enjoy unprecedented network performance and management with the help of private 5G. 5G mmWave plays a crucial role in delivering focused high-performance service for cars, people, and devices in motion throughout cities for those applications that may benefit from public mobile network access. Companies that deploy Internet of Things (IoT) apps across vehicle fleets may benefit from 5G mmWave's enhanced data rates and reduced latency by employing the technology to speed up the discovery process for predictive analytics conducted through their mobile network. [58]

1.13.5 mmWave Problems for 5G

- Challenges exist while working with MmWave transmissions. Due to the lower wavelength of mmWave transmissions, their range is much less compared to that of low-band or Sub-6 5G.
- MmWave transmissions are more dependent on line of sight and so need a fiber backhaul.
- Finally, obstacles such as glass, walls, buildings, and thick vegetation make it difficult for mmWave signals to go through them.
- The bright side is that there are several approaches to overcoming these constraints. First, think about whether or not mmWave will help you achieve your objectives. To fulfil your service-level objectives, mid-band 5G may provide the speeds and coverage you need in certain situations.
- Expanding mmWave coverage through a system of tiny cells and repeaters is an option where latency and throughput are critical. Indoors, for instance, weak mmWave signals may be amplified by tiny repeaters, which significantly improves performance and coverage. Adding more tiny cells to the 5G mmWave network is another way to boost coverage.
- Due to the greater infrastructure requirements compared to mid- and low-band broadcasting, many companies reserve the mmWave spectrum for just the most demanding of applications

1.13.6 mmWave 5G for Business Networks

Celona is the first company to provide a complete turnkey solution for corporate companies to construct their own private 4G LTE and 5G networks. Celona networks powered by private spectrum options (such as CBRS in the United States) provide a means to enhance control, security, and performance for mission-critical use cases within the enterprise, in addition to applications and devices supported by 5G mmWave technology in public mobile networks. Celona 5G LANs simplify the out-of-the-box experience, allow for large-scale network operations, and allow for onboarding to occur concurrently with existing wireless and IT infrastructure without disrupting corporate operations.[59]

1.14 Designing Tool

1.14.1 CST Microwave Studio

CST MICROWAVE STUDIO, also known as CST MWS, is an electromagnetic 3D high-frequency simulation tool of exceptional quality. The user is able to evaluate high-frequency components, such as antennas, filters, couplers, planar and multi-layer structures, as well as SI and EMC effects, in a manner that is both speedy and reliable with the help of CST MWS. The software provides users with access to solvers that operate in both the time domain and the frequency domain respectively. When it comes to certain applications, CST deals with a greater number of solver modules. Import filters that simplify complex CAD files and the extraction of SPICE parameters accelerate the process of improving design possibilities while simultaneously saving time. CST offers accurate and efficient computational solutions for electromagnetic design and analysis. The intuitive interface of our 3D EM simulation software guides you through the process of determining which strategy will be most effective when it comes to the design and optimization of frequency-independent systems.

1.15 Inspiration

Since the advent of wireless communication, it has grown in popularity due to its affordability, adaptability, mobility, and many other qualities. Consequently, there has been a quick the recent increase in mobile data traffic, data rates, and connection requirements for thirty years. Once more, the Internet has given these demands a new dimension. Things of (IoT). The telecoms sector has developed practically every decade. from many generations of standards in order to satisfy this expanding need. Consequently, the fifth generation (5G) is anticipated to fulfill more than 100 billion people's connectivity needs. Internet of Things, wireless devices, low millisecond latency, 10 Gbps data throughput, etc. were released at the beginning of the 2020s [11]. Among the major obstacles to the adoption of Path-loss in high frequency caused by 5G inspired us to create an antenna that can overcome this difficulty.

1.16 Essence

The telecommunications sector is developing quickly. A new generation emerges roughly every ten years. The previous one, 5G, is the one that researchers are most interested in. With the enormous growth of wireless apps, technology has advanced from the fourth generation (4G) to the fifth generation (5G). Wireless networking standards will adopt the 5G specifications, which are the successors of 4G/IMT-Advanced, next. With a higher density of wireless network users and a higher capacity than the current 4G standard, 5G might support the Internet of Things, large-scale computers, and ultra-reliable communication (IoT). We must build antennas that are 5G compatible since wireless communication is impossible without the use of an antenna. Due to its distinct qualities, the microstrip patch antenna is currently the most widely used antenna in wireless communication. The reduced size of this type of antenna makes it suitable for tiny end devices. Any PCB can readily be used to etch antennas based on microstrips. Microstrip patches come in a variety of shapes, such as rectangular, circular, triangular, etc. Because they may be generated in large quantities, their processing costs are reduced. They can accommodate many frequency bands (dual, triple). Both linear and circular dual polarization variants are accepted. They are light in weight.

The new 4G network employs sub-6-GHz frequencies for connectivity. However, the available spectrum in these bands is insufficient to meet 5G requirements [11]. Therefore, we must switch to bands with higher frequencies in the range of 6 to 300 GHz. As a result, the Federal Communications Commission designated the following bands for 5G wireless communication: 3.4-3.6 GHz, 5-6 GHz, 24.25-27.5 GHz, 37-40.5 GHz, and 66-76 GHz [12] bands, as well as 27.5-28.35 GHz for 5G [12] bands [11]. Designing high-gain microstrip patch antennas for 5G communication at 28 GHz has been the subject of several studies [14–19]. However, some of those antennas do not fully cover the 28 GHz bands, as stated by the FCC, and others are too wide to work with 5G mobile phones. Designing an antenna that will cover the 28 GHz range and be compatible with 5G smartphones is therefore essential.

Chapter 2
Literature Review

2.1

2.1.1 Understanding the 3GPP Release 15 and 16 5G Standard

3GPPTM began defining 5G New Radio (NR) in late 2015 to fulfil ITU-R criteria. The standardization project involves channel modelling of the 100 GHz spectrum, which has the potential for increased bandwidth allocation, faster throughput, and reduced latencies. It also entailed exploring next-generation radio access technologies and their components. 3GPP releases each step of standardization. Release 15 of 5G NR enables improved mobile broadband and basic URLLC in a spectrum up to 52.6GHz. Release 15 originally appeared in December 2017. [29]

2.1.2 5G NR Spectrum

Given the insatiable consumer demand for mobile data and higher throughput rates and the vast amount of spectrum available in the 3 to 100GHz spectrum region, regulators and standard organizations considered opening and using centimeter wave (cmWave) and millimeter wave (mmWave) regions for mobile communication and developing a framework for spectrum sharing with incumbent technologies. Release 15 of 3GPP defines two frequency ranges: 450 MHz to 7.125 GHz for FR1 and 24.25 to 52.6 GHz for FR2 (Table2.1). The availability and regulatory requirements of spectrum in the 52.6 to 114.25GHz band are being studied, as are use cases and implementation scenarios. [43]

TABLE 2.1 DEFINED FREQUENCY RANGE

FREQUENCY RANGE DESIGNATION	FREQUENCY RANGE	MAXIMUM CHANNEL BANDWIDTH
FR1	450MHz to 7.125GHz	100MHz
FR2	24.25 to 52.6GHz	400MHz
UNDERSTUDY	52.6 to 114.25GHz	TBD

2.1.3 mm-Waves

Problems arise while transitioning to mm-Waves because of the features of the radio channel and the fact that attenuation is greater for waves with shorter wavelengths (for example, because of atmospheric circumstances). On the other hand, dozens or hundreds of antenna elements may be used in mmWave antenna arrays by taking advantage of shorter wavelengths with smaller antenna array elements that can be packed together more densely. By designing antenna systems with high gains and narrow beams, we can combat the greater losses seen by mmWaves and, in certain cases, minimize interference. [25]

2.1.4 Optimization of Throughput

Higher throughput is attained with the help of NR's exploitation of the following methods:

- This means a greater percentage of the available spectrum is being used. The transmission bandwidth to the channel bandwidth, including any outside guard bands, is defined by the spectrum's use. Currently, 90 percent of the available spectrum is being used for Long Term Evolution (LTE) communications, but with NR, that number may rise to 98 percent.
- Increased subcarrier occupancy after performing a fast Fourier transform (FFT). The percentage of subcarriers in use after FFT in LTE is around 60%. In a 20MHz LTE system, for instance, 1,200 of the available 2,048 subcarriers are used for the FFT. Besides the increase due to increased spectrum use, the number of occupied subcarriers rises by an additional 25% in NR. Keeping the FFT size and subcarrier spacing the same, the channel bandwidth increases by 25%.
- Enhanced FFT size. Increasingly sophisticated ICs allow the support of bigger FFT sizes. The maximum FFT size in NR is 4,096, making it almost twice as large as LTE's maximum.

- The wider separation between subcarriers. LTE uses 15 kilohertz of single subcarrier spacing for data transfers (kHz). The highest subcarrier spacing in NR is 120kHz, which improves the channel bandwidth by a factor of eight without increasing the number of subcarriers. The maximum subcarrier spacings permitted for data transmissions in FR1 are 15kHz,
30kHz, and 60kHz; in FR2, the maximum subcarrier spacings permitted are
60kHz and 120 kHz [43]

2.1.5 5G NR Physical Layer Aspects

Channels and transmitted signals in 5G NR are distributed across separate subcarriers in an orthogonal frequency-division multiplexed (OFDM) air interface. With regard to multiple-access schemes, NR has settled on OFDM access. Without multiuser multiple input, multiple outputs (MIMO), different users are assigned to separate subcarriers for downlink and uplink broadcasts.

CP-OFDM, which stands for "cyclic prefix orthogonal frequency division multiplexing," is the waveform used for both downlink and uplink broadcasts in NR. Because of the low peak-to-average power ratio (PAPR) of the DFT-S-OFDM waveform for user equipment (UE) in power-limited zones, it is also employed in the uplink. The single-layer uplink is required for DFT-S-utilization. OFDM's For DFT-S-OFDM, a signal is precoded using DFT before it reaches the subcarriers used in the transmission. Once the OFDM symbol is converted back to the time domain, a CP is added to it. [25]

2.1.6 Subcarrier Spacing

5G New Radio (NR) is a uniform air interface that works with a wide range of frequencies, from sub-1 GHz to tens of GHz (about two orders of magnitude). Typically, the bandwidth-to-carrier-frequency ratio scales in a linear fashion with the carrier frequency. If just the subcarrier counts for the various channel widths are considered, the multiplexing granularity will suffer for the narrower channels. Hardware complexity rises in this situation because bigger FFT/inverse FFT (IFFT) blocks are needed when several subcarriers are used to cover a wide channel bandwidth. However, a wide variety of channel bandwidths may be supported while still keeping the subcarrier spacing within a tolerable range. Subcarrier spacing may be any of 15, 30, 60, 120, or 240kHz (with 240kHz reserved for synchronization signals and the broadcast channel), and is built to scale in powers of two. [25]

2.1.7 Transmissions with Minimal Delay

5G New Radio (NR) includes a number of technological enhancements meant to facilitate low-latency operations.

- Lower latency is achieved by shorter symbol and slot durations, which are made possible by a larger subcarrier spacing.
- In the case of the short physical downlink-shared channel and physical uplink-shared channel broadcasts, as few as two symbols are supported.
- A 5G NR network can optimize a downlink and uplink transmission time depending on the UE's processing capabilities and the latency needs of associated

traffic thanks to its support of a flexible scheduling and timing framework with varying UE processing capabilities.
- With the use of prepared uplink resources (such as a configured grant), the UE may send uplink data without any assistance from the base station. [25]

2.1.8 Transmitting Data Through a Channel Using Codes

For data and control channels with a payload of 12 bits or more, 5G NR introduces additional channel coding schemes:

- Low-Density Parity-Check (LDPC) codes are supported by 5G NR for use in data channels.
- Polar codes are supported by 5G NR for control channels with a payload of 12 bits or more.
- 5G NR allows for the use of Reed-Muller codes for control channels with a payload size of 3-11 bits.
- 5G NR supports Repetition and Simplex codes for 1-bit and 2-bit control channels.[25]

2.1.9 Massive MIMO for 5G New Radio

Massive MIMO is the most recent iteration of the MIMO technology, and it is used in 5G NR to build antenna arrays with more components. Increased wireless capacity is the goal of massive MIMO, which does this by increasing spectral efficiency through higher-order spatial multiplexing and expanding wireless coverage via beamforming. For huge MIMO, 5G NR designed a scalable and adaptable architecture that can:

- Carrier frequencies below 1 GHz and up to millimeter waves
- Varieties of Antenna Array Structures (digital, analog, and hybrid)
- Multiplexing using frequency division duplex (FDD) and time division duplex (TDD)

With the goal of optimizing its MIMO architecture, 5G NR uses two approaches to improve spatial multiplexing:

- The first is to design a system that allows for the use of numerous antenna ports for channel transmission, thereby allowing for multiple transmission layers to be used.
- The second is to take channel measurements to identify the channel's rank, and then use that data to precode the transmission layers across all of the transmitter's antenna inputs for maximum throughput.[29]

2.2 Paper Review

In this section, we will evaluate the work performed by other researchers in regard to this thesis, "Design and Simulation of Highly efficient circular ring microstrip Patch Antenna for 5G Wireless Data Transmission." This is a key component for continuing research on the mobile use of antennas of the current fifth-generation (5G). As a consequence, development for the design and modelling of an antenna has become more productive and straightforward.

1 Overview of 5G antennas: design, advancements, and applications

As the need for more data increases, the most advanced wireless technology is now fifth-generation (5G). Among the key objectives of the 5G communication system are increased data rates (up to 20 Gbps) and availability, ultralow latency (1 millisecond), high dependability, great flexibility, and enhanced device-to-device communication. The millimeter-wave (30-300 GHz) frequency spectrum has been the focus of 5G wireless networking research for the aforementioned reasons. For the development of such high-throughput, low-latency, and flexible systems, antenna design is crucial. In this paper, we present a complete review of 5G antenna designs and fabrication procedures for a variety of substrates, including Rogers RT/droid 5880, Rogers RO4003C, and Taconic TLY-5. The numerous applications for which antenna arrays, MIMO antennas, phased antennas, and beamforming antennas are ideally suited are reviewed in detail. To maintain the requisite gain, efficiency, and isolation in 5G MIMO antennas intended to occupy less area, mutual coupling reduction techniques are required. In addition to the variety of MIMO antennas and approaches for reducing mutual coupling, this research's primary foci include these topics:[44]

2 Design and Simulation of a Single Element High Gain Microstrip Patch Antenna for 5G Wireless Communication

Due to its large bandwidth, the millimeter-wave (mmWave) spectrum might be used in 5G mobile communications. In mmWave bands for indoor use, especially in the 31.8 to 33.4 GHz range defined by ITU for 5G, an efficient, reliable, and accurate channel model is important. This article details a planning and characterization operation at 32 GHz in a university office in Karabuk, Turkey. Straight, ground-reflected, and ceiling-reflected pathways create an indoor 32 Gigahertz small-cell backhaul network. Three-ray models are near approximations. The statistics include route loss, shadowing, RMS latency dispersion, RMS angular stretched, power angular band, number of clusters, and Ricean K-factor in a wide-open interior situation. Energy angular spectrum analysis reveals transmission structure. They say the results will help model and design 32 GHz 5G mobile systems. [19]

3 Analysis document on, “Design of 28/38 GHz Dual-Band Triangular-Shaped Slot Microstrip Antenna Array for 5G Applications.

This research presents dual-band array antennas with one, two, four, and six elements. The 5G antenna array enables dual-band response at 28 GHz and 38 GHz, according to the results. A single-element antenna gains 5.75 dBi at 28 GHz and 7.23 dBi at 38 GHz. Six-element arrays are best. 7.47 to 12.1 dBi gains are possible. Radiating components (array) may affect antenna gain. [21]

4 Analysis document on, “A New 2x4 Array Design of Dual-Band Millimeter-Wave Antenna for 5G Application

In this research, a 2x4 array antenna for usage at both 28GHZ and 38 GHz in the millimeter wave band was constructed and tested. The proposed antenna array has a 4x4 layout and consists of 8 distinct nodes, each with its own set of ports. Through the slotted patch approach, dual-band capabilities have been attained. Comparisons are made between SMA channel feeding and waveform techniques, as well as antenna gain. Using the SMA connection, the antenna array gain is 15.8 dBi at 28 GHz and 13.9 dBi at 38 GHz. The antenna's gain fell somewhat when the waveguide feed was replaced with an SMA connection. Each of the eight antenna segments used to cover the 28 GHz and 38 GHz bands have very consistent return-loss (S11) characteristics. In addition, there is sufficient space between each component, with a separation of more than 28,692 dB at 28 GHz and 38,779 dB at 38 GHz to fulfil inter-element shielding criteria. [22]

5 Analysis document on, “Slot-Based Connected Antenna Arrays for 5G Mobile Terminal

Using the concept of linked antenna arrays (CAA), this research proposes an antenna array design that is both visually appealing and small in size. The CAA approach enables more compact antennas that may be incorporated into wireless communication network terminals, in addition to wideband antenna responses that are well suited for millimeter-wave applications. This study proposes a slot-based linked antenna array for standard-sized mobile cell terminals that encompasses both 4G and 5G millimeter wave band antenna systems. The 4G spectrum operates between 1.8 and 3.1 GHz, and the 5G range operates between 27.2-28.5 GHz [23].

6 "Substrate Integrated Gap Waveguide Circularly Polarized Slot Antenna" analysis paper

In this publication, researchers suggest a substrate-integrated gap waveguide (SIGW)-based broadband aperture circularly polarized antenna for 5G millimeter wave applications. A slanted aperture is attached to the metal layer of the SIGW, and the SIGW's microstrip transmission line provides the excitation. The mechanism of circularly polarized radiation will be examined soon. The simulated findings reveal a bandwidth of 10 dB from 24.8 to 31.7 GHz and a bandwidth of 3 dB for the axial ratio from 27.3 to 28.8 GHz [24].

7 "Radiation Performance Analysis of 28 GHz Antennas Integrated into 5G Mobile Terminal Housing" is the title of this analysis paper.

In this research work, many possible 28 GHz antenna components for a 5G mobile terminal are incorporated. The terminal housing impacts diminish the radiation properties of the studied 5G antenna components. Initially, the impacts of guided waves, superstrates, surface currents, and the mobile user's hand are discovered and assessed individually on 5G millimeter wave mobile phone antennas. Using the inverse source approach, EQCs are generated that provide a novel perspective for supporting the design of 5G mobile phone antennas in MHTE. EQCs have a high degree of concordance between measurement and simulation. Terminal housing impacts on the array and subarray performance are evaluated via the coverage efficiency and the suggested effective beam-scanning efficiency. The design of 5G mobile phone antennas must take these factors into account. Similar to the coverage efficiency, effective beam-scanning efficiency may be favourable performance indicator for 5G beam-scanning mobile phone terminals [25].

8 "Broadband Elliptical Slotted Patch Antenna for 5G Communications" analysis paper

An elliptical slotted broadband patch antenna is suggested in this article for future 5G communications. The suggested antenna has a surface area of 4,2 mm2 and a height of 0.127 mm. Using a 50-ohm microstrip transmission line feeding approach, a rectangular ground with an elliptical slot and a T-shaped slotted patch are created. The developed antenna spans the whole frequency range from 22 GHz to 48 GHz, which comprises three 5G frequency bands, with the necessary gain and omnidirectional radiation pattern. The planned antenna array achieved about 18 dBi gain at 28 GHz and 21 dBi gain at 38 GHz. This paper's suggested antenna is a viable choice for future 5G wireless communications [26].

9 “Document of analysis titled "Design of a Tri-Band Microstrip Patch Antenna for 5G Application."

In this article, a triple-band microstrip patch antenna for future 5G mobile communication is presented. Rogers RT Duroid-5880, which has a relative permittivity of 2.2 and a thickness of 0.25 mm, is utilized as the antenna substrate. Two distinct commercial electromagnetic modeling software, IE3D and HFSS, are used to build and simulate the predicted antenna and then compare the results. Simulation findings indicate that the constructed antenna produces a reflection coefficient more than 10 dB across three 5 G bands. The greatest gain at 24.4 GHz, 28 GHz, and 38 GHz is 6.65 dBi, 7.02 dBi, and 5.05 dBi, respectively [27].

10 "Empty Substrate Integrated Waveguide Slot Antenna Array for 5G Applications" analysis document

In this study, a slot array antenna based on the unique structure of an Empty Substrate Integrated Waveguide (ESIW) is presented. The developed antenna operates in the 28 GHz frequency with little loss and great efficiency. It has increased the feasibility of practical use in mobile phones in a manner that is both cost-effective and relatively simple with regard to the planar design and modeling of antennas and their integration in mobile phones. A 10 dB bandwidth of about 2.9 GHz enables the proposed antenna to operate between 26.5 GHz and 29.4 GHz. The maximum gain attained at 28 GHz is 11.6 dBi [28].

11 Compact Size MIMO Amer Fractal Slot Antenna for 3G, LTE(4G), WLAN, WiMAX, ISM, and 5G Communication: A Document of Analysis

The Amer fractal slot antenna is a multiple input, multiple output (MIMO) antenna with four ports suggested in this study. In the design of the suggested MIMO, the Amer fractal slot structure was used to offer many surfaces current routes, whereby each path produces its own resonant frequencies, which together provide a wide working range. Some of these pathways are perpendicular to one another, resulting in circular polarization, low reciprocal relation for all operating bands (almost 1.5-30 GHz) between opposed ports (1 and 3, 2 and 4), and less than -10dB for all neighboring frequency band ports (nearly 1.5-30 GHz) (15-30 GHz). The measured performance varies from 50 to 85 percent for tiny and low-profile devices. The antenna may thus handle several wireless networking devices, including 3G, LTE (2.6/3.5 GHz), Wi-Fi (2.4/5GHz), WiMAX (2.5/3.5/5 GHz), ISM (24/5 GHz), and 5G. (GHz 5-6 and GHz 27-28) [39].

12 "Single-feed Dual-band Aperture linked Antenna for 5G Application" analysis paper

The design and modeling of a lightweight, high-gain, single-feed, dual-band antenna for 5G applications is suggested in this study. The projected antenna consists of a 28 GHz, 6.25 dBi slot antenna and a 38 GHz, 8.5 dBi patch antenna. The crosspolarization frequency of both antennas is less than 48 dB, and their estimated bandwidth is 2 GHz [41].

13 "Reconfigurable Slot Antenna Design for 5G Smartphones with Metal Casing"

This study proposes a reconfigurable slot antenna to span a large bandwidth of 824-960 MHz, 1710-2690 MHz, 3300-3600MHz, and 4800-5000 MHz for smartphone software of the fifth generation (5G). The suggested antenna has achieved enough impedance bandwidth and overall performance across all required frequency ranges. The finding implies that a metal-encased 5G smartphone is a suitable option for the suggested antenna [23].

14 Eight-Antenna Array in the 5G Smartphone for the Dual Band MIMO System: A Document of Analysis

This work presents a tiny dual-band slot antenna for constructing multiple-input multiple-output (MIMO) antennas. The suggested antenna demonstrates two broad operating bands for 5G mobile connectivity. The antenna demonstrates excellent efficiency, and the MIMO system operating in the operational spectrum accepts ECCs (3.3-3.6 GHz and 4.8-5.0 GHz) [32].

15 5G mm-wave Antenna Array Based on T-slot Antenna for Mobile Terminals: Analysis

Based on the T-slot antenna, a phased-array antenna system for mobile terminals is presented in this study. The return failure, radiation, and scanning characteristics of the T-slot antenna are addressed. T-slot antennas provide a more consistent antenna gain than rectangular slot antennas, making them more appropriate for 5G mm-wave mobile terminal applications [35].

16 "Design of a Dual-Band MIMO Antenna for 5G Smartphone Applications"

Dual-band, four-antenna MIMO array for 5G mobile applications is proposed in this study. The proposed antenna is comprised of four antennas that operate at 3300-3600 MHz and 4800-5000 MHz. In accordance with the trend toward a full-screen smartphone antenna design, the proposed antenna is positioned in the side frame. Based on the assumption that the reflection coefficient meets the requirements, and in order to achieve a reasonably high level of isolation, the antenna size is relatively small, making it suitable for ultra-thin smartphone communications [44].

17 "60 GHz Array Antenna for mm-wave 5G Wearable Application" analysis paper

In this article, a 60-GHz array antenna for wearable mm-wave 5G applications is suggested. The suggested antenna's radiation pattern is a fanbeam for wide radiation coverage. Simulated 3-dB and 10-dB beamwidths in the xz-plane measure 38.9 dB and 142.9 dB, respectively. Even though the beam is directed, the radiation parameters of the antenna on the phantom of the human head are well retained. The suggested antenna might be a viable alternative for 60 GHz 5G wearable applications [46].

18 “Document of analysis titled "Printed Millimeter-wave MIMO-Based Slot Antenna Arrays for 5G Networks."

For future 5G networks, a simple mm-wave MIMO slot antenna system comprised of two three-element metal arrays has been devised in this research. The EBG reflector was used to reduce back radiation and boost the F/B ratio. The design development of the suggested MIMO antenna system was explained using a performance study. Over a broad impedance bandwidth of more than 81.7%, the proposed design exhibited high insulation, ranging from 22.5 to more than 50 GHz for 10 dB return loss, and provides low envelope correlation values over the entire operating band, while peak gains were greater than 11.5 and 10.9 dBi at 28 and 38 GHz, respectively. Due to its low size and adequate performance, the suggested antenna is competitive for future 5G networks [47].

19 "Single Feed Compact Millimeter Wave Antenna for Future 5G Applications" analysis paper

Printed on a low-cost dielectric substrate (RT droid 5880) and resonating at two frequencies - 28 GHz and 38 GHz - a single-layer compact planar antenna has been presented in this study for future 5G wireless transmission applications. The finite element method (FEM) of Maxwell's electromagnetic equations and the parametric research revealed a peak gain of 8.05dB, a bandwidth of 921MHz at the 28 GHz band, and peak gain of 8.28dB, a bandwidth of 1.0451 GHz at the 38 GHz band. Moreover, the concept of combining undesirable narrow bandwidths improves the bandwidths for both resonance frequencies greatly. [29]

20 Small Form Factor PIFA Antenna Design at 28 GHz for 5G Applications: A Document of Analysis

This work offers the design and analysis of the lowest form factor planar Inverted-F Antenna at 28GHz for possible 5G Mobile applications. For antenna feeding and shorting, metallic strips are used. The important characteristics of this antenna are its tiny footmark (0.25g), 4.5dBi gain, 1.55 GHz impedance bandwidth of 10 dB, and 94% radiation efficiency. The total mass of the PIFA antenna is 0.25g. The effectiveness of PIFA antennas is highly dependent on the size and position of the ground plane. When situated in a corner or on a side, it emits a powerful radiation pattern. The PIFA antenna is installed on a 0.8 mm thick FR-4 substrate. To increase the bandwidth, extra parasitic elements may be added [30].

21 Document of analysis for "A SAR Reduced Mm-Wave Beam Steerable Array Antenna with Dual-Mode Operation for Fully Metal-Covered 5G Cellular Handsets."

In this work, a small, dual-mode, 28 GHz beam-driven array antenna for a 5G smartphone with a full metal coating that achieves the desired absorption rate is presented (SAR). The proposed antenna features a total of eight rotating antenna components distributed across the device's top frame and back cover. The selection of a switch that decides which subarrays to employ is influenced by modalities. In the frequency range of 27.2 to 28.2 GHz, the proposed array exhibits low mutual couplings between the antenna components (-11.8 dB) and high refractive index coefficients (-0.9). The proposed antenna offers exceptional beam control and hemisphere-spanning coverage. At 24 dBm of input power per subbarray, the peak SAR on the head phantom is found to be 0.53 W/kg for a beam scan angle of 0 degrees and 0.88 W/kg for a scan angle of 40 degrees. [31]

22 Compact and Low-Cost 3D-Printed Antennas Metalized using Spray-Coating Technology for 5G Mm-Wave Communication Systems

This study provides suggestions that leverage low-cost EMI/RFI spray-coating technology to metalize 3D-printed antennas with high gain, high power, and low weight. By employing EMI/RFI conductive paint, the antenna's production costs and complexity are lowered, but the antenna's performance in the 28 GHz band is satisfactory. In this study's conclusion, the unique manufacturing method makes the suggested antenna a possible contender for low-cost 5G mm-wave mobile applications [32].

23 A millimeter-wave connected antenna array for 5G applications: an analysis

This study proposes a revolutionary wide-band printed wired antenna array design at 28 GHz for future 5G wireless communications with a high data transmission rate. The construction of the mobile phone antenna was flat, small, and thin. Using a 4?? 4 Butler matrix for 4 switched beam locations, it obtained peak gain ranges of 4.29 dBi to 6.68 dBi [33].

24 "A Novel Connected PIFA Array with MIMO Configuration for 5G Mobile Applications"

Fictional volume This research demonstrates that a coupled PIFA MIMO antenna might be employed in future 5G wireless networks. The antenna consists of four distinct multi-input multi-output (MIMO) antennas, each with an accompanying 8-element array. Likewise, each array is composed of eight printed Inverted-F antennas (PIFA). The plot of the antenna's reflection coefficient demonstrates that it operates in the 5G 28 GHz band with a bandwidth of around 1 GHz. Maximum gain is 12 dBi, while emission efficiency is 85 percent. [34]

25 Document of analysis titled "Modified Triple Band Microstrip Patch Antenna for Higher 5G Bands"

This work describes the design of a modified three-band microstrip patch antenna for higher 5G frequency bands running at 28 GHz. The antenna is intended to be 30x40x1.6 mm wide on an RT/Duroid 5880 substrate with a dielectric constant of 2.2. The proposed configuration of the antenna resonated at 28 GHz, 31.45 GHz, and 34.6 triple frequencies with return losses of -12.5114 dB, -16.5928 dB, and -15.7107 dB, respectively, and covered a 10 dB impedance bandwidth of 1.37 GHz (27.47-28.84 GHz) at 28 GHz, 0.11 GHz (31.38-31.49 GHz) at 31.45 GHz, and 3 In addition, the overall gain of 3.7308 dB and the VSWR of 1.6206 are less than 2, making them ideal for a high-frequency antenna to be utilized in the United States, Korea, and Japan with a minimum signal loss of 28 GHz [35].

26 Analysis of "A Novel 28 GHz Beam Steering Array for 5G Mobile Devices with Metallic Casing"

In this study, the design of a modern, realistic 28 GHz beam steering array antenna for potential 5G mobile phone applications is presented. The proposed array antenna consists of two eight-step arrays, one on each side of the mobile device, and sixteen cavity-backed slot antenna components connected through the metallic back enclosure. Each 8-element phased array may achieve a gain of more than 15 dBi at boresight and deliver wide-angle beams. The planned cavity-backed antenna has a return loss frequency of 10 dB between 27.5 and 30 GHz. [36].

27 "Compact Quad-Mode Planar Phased Array with Wideband for 5G Mobile Terminals" analysis paper

In this research, a quad-mode end-fire planar phased antenna array with a large scanning angle and 1.2 mm clearance is presented for 5G mobile terminals. The suggested antenna's impedance bandwidth may exceed 8 GHz. This study suggests combining a multimode array element with various radiation patterns for each mode into an antenna array in an effective manner. In the array, similar and extensive embedded radiation patterns are created for all four modes. In addition, this study gives a transition from coaxial to differential stripline. The differential feed topology is very small and utilizes just MMPX connectors and vias. In the frequency range of 25 GHz to 33 GHz, the total scan pattern and coverage efficiency of the measured and simulated phased array antenna are calculated, and excellent agreement is seen between the measured and simulated findings. The variance of the coverage efficiency throughout the frequency spectrum exhibits modest changes, despite the similarity of the mean coverage efficiency. In the selected frequency range, a threshold gain of 5 dBi yields a coverage efficiency of around 50 percent.[37]

28 Analysis of a dual-band 28/38 GHz millimeter-wave SIW array antenna with EBG structures for 5G applications.

The construction of a linearly polarized antenna/array dual-band integration waveguide (SIW) operating on the Ka-band is being studied. One of the aeroplane's planes is etched with a SIW core, while the other plane features transverse and longitudinal slots. This is the antenna's sole characteristic. For the longer and shorter slots, the resonant frequencies are 28 GHz and 38 GHz, respectively. Only the outcomes of simulations may be shown. All simulations were conducted with the aid of CST Microwave Studio, which is an industry-standard piece of software. Single antenna components may achieve an impedance bandwidth (S 11 dB; -10 dB) of 0.45 GHz (1.60%) and 2.20 GHz (5.78%), with a maximum gain of 5.2 dBi at 28 GHz and 5.9 dBi at 38 GHz. This is achieved by the use of a notch filter. To achieve high gain, a horizontally polarized linear array of four components (14) has been developed. For the antenna array to feed the microstrip line network, an Wilkinson power divider with a 3 dB gain is employed. The impedance bandwidth is 0.32 GHz (1.14 %) at 28 GHz and 1.9 GHz (5 %) at 38 GHz, while the maximum gain at each frequency is 11.9 dBi and 11.2 dBi, respectively. In the given designs, the substrate RT/Duroid 5880, which has a low cost and loss, is used. [38]

29 Document of analysis titled "mmWave Novel Multiband Microstrip Patch Antenna Design for 5G Communication.

This research aims to develop a unique mmWave multiband patch antenna for usage in 5G communications. When set to resonate at these frequencies, the 5G mmWave antenna has a high throughput of 5.5 GHz in the 37 GHz band and 8.67 GHz in the 54 GHz band. The 5G mmWave multiband antenna is designed using microstrip technology, resulting in the antenna's small weight, low cost, low profile, excellent performance, and high efficiency. For the construction of the 5G antenna, the CST MWS modelling software is used. It has an extremely compact form factor, with dimensions of 7.2 to 5.0 to 0.787 mm3. The 5G multiband antenna has successfully achieved an acceptable gain, measuring 5 dBi and 6 dBi, respectively. It is simple to implement and can be used for 5G connectivity in a wide range of mobile devices [39].

30 Dual-band Microstrip Patch Antenna Array for 5G Mobile Communications: An Analysis

This study presents a description of dual-band 5G communication utilizing the 8-element microstrip patch antenna (MPA) series. The proposed antenna array is modest, measuring

16 mm in diameter at 28 GHz and 16 mm in diameter at 38 GHz. To provide dual-band response, a U-shaped slot with an inverted aperture may be etched into the main radiator. According to the investigation's findings, the proposed array is capable of producing resonance for the frequency ranges of interest. In tandem with this, the proposed antenna array emits in both directions and provides enough gain across both frequency bands [40].

31 Highly Effective 2x2 Antenna Array for 5G Applications at 28 GHz and 38 GHz

The design of microstrip patch antennas (MPAs) to match the requirements of 5G networks is cited as one of the current most challenging challenges in this study. This project aims to produce a high-performance, 2x2 antenna array for 5G standards that operates at 28 GHz and 38 GHz. Although previous tests suggested that MPA antennas could not sufficiently meet 5G criteria, their extensive use in new connections was due to its low price, compact size, and ease of production. This work contains a 2x2 antenna array at 28GHz and 38GHz. Foam was utilized as the substrate element in both antenna designs, with a substrate height of Hs=0.5 mm, and both utilised quarter-wave transmission. Bandwidth, return loss, realized gain, VSWR, and antenna efficiency of the proposed 2x2 antenna array are 1.3 GHz, 61.19 dB, 15.4 dB, 1.001, and 97.97% at 28 GHz, and 2.49 GHz, 52.28 dB, 13.8 dB, 1.005, and 97.97% at 38 GHz, indicating outstanding performance. Compared to previous research, it was discovered that the suggested antenna array provides improved coverage for all goals [52].

32 5G Applications Novel and Compact Circular Ring Microstrip Antenna with Parasitic Chip

In this study, scientists say, a circular patch antenna has been constructed, and parametric research has been conducted using a number of geometric factors. In the second part of the procedure, a parasitic chip is put on top of the planned circular patch antenna in order to increase the gain and overall efficiency of the antenna. This makes it perfect for usage in 5G applications. The CST Studio Electromagnetic (EM) simulator is used to simulate the antenna with and without the parasitic chip, as well as to analyze its performance. This antenna has a tiny footprint of 10 by 10 by 1.547 mm3, a straightforward manufacturing technique, broadband characteristics up to 3.31 GHz with a high gain of up to 6.87 dB, an overall efficiency of 95%, and a minimum return loss of -68.02 dB over the operating frequency range. In order to examine and certify the antenna's overall quality, a simulation based on both the frequency and time domains is conducted and a good agreement is reached [53].

2.3 Summary

Several research has been carried out in order to produce a dual-band patch antenna by using a slot antenna for each individual band. Other investigations have also been carried out. According to the most recent findings, it is abundantly clear that among the various millimeter wave bands, the most promising and significant candidate for 5G wireless communication can be found. This is because a significant amount of research has been carried out that covers the frequency bands in question. Again, the most difficult problem associated with the implementation of 5G is to build a high-gain slot antenna that can withstand extreme path loss, be sufficiently tiny to be able to integrate easily and be easy to manufacture into mobile phones.

2.4 Objectives

1. The main aim of this work is to design a compact size and a simple microstrip patch antenna operating within the V band frequency range and fulfilling the requirements for wireless mmwave networks.

2. We want to achieve High Gain, High Directivity with a miniaturized mmwave Antenna.

3. We also want to achieve a Higher Return Loss (S11) with our proposed Antenna

4. We also want our Antenna to be Highly Efficient.

5. The use of mmWave signals in 5G enables intense improvements in speed and latency. our goal is to achieve those improvements.

Chapter 3
Methodology

3.1 Methodology of Research

When we talk about "methods," we're referring to a specific category of "particular procedures or approaches." Recognize, select, assess, and interpret data pertinent to a topic area is the main purpose of this function. When writing a report on research, a user may also use the term "methodology" to aid the reader in critically evaluating the overall validity and dependability of a study. This may be done to assist the reader in understanding how the study was conducted. The term "qualitative methodology" refers to one of the subfields that fall under the umbrella of "methodology," while "quantitative methodology" describes the other. It is possible to use a qualitative method in order to get an understanding of the viewpoints that individuals have in relation to an event that has taken place or a candidate who is running for president. Take, for instance, the following: if we may express such an example as: In order to understand people's points of view, Quantitative methods, on the other hand, are often used as the method of choice when the objectives and goals of the research are of a confirmatory character.

3.2 The conceptual framework behind the research design

The general approach that the researcher will follow in order to try to respond to the study question is referred to as the research design. In many cases, developing research questions necessitates developing a study approach. Please include a description of the sources that were utilized in your research. For instance, the experimental design, the methods for data collection, and the strategy for statistical analysis are all instances of such features.

3.2.1 In the course of this research, the following studies were developed:

- An investigation into the process of shifting from 4G to 5G in its entirety.
- Investigate the essential antenna parameters for 5G networks.
- Carry out research on the material that has been published on slot-based microstrip patch antennas, in addition to researching contemporary 4G and 5G antennas.
- It is recommended that you look into the design of a process slot-based (MPA) antenna.
- Conduct an investigation on the steps involved in creating antennas using CST Microwave Studio.
- Calculate essential parameters to design the antenna.
- Putting the process into motion is something that has to be done.
- Start the procedure again from the beginning.

3.3 Pilot Study

Before launching a large-scale research endeavour, it is customary to do a "pilot study," "pilot project," "pilot test," or "pilot experiment" to evaluate its capacity, length, cost, unfavourable outcomes, and improve its nature. It is performed prior to doing the real research. Typically, early investigations are conducted in line with the study's established agenda. A pilot study cannot eliminate all types of errors, but it may reduce those that would otherwise render the first study a waste of time and money.

3.3.1 Importance of Pilot Study:

- To apply the study's methodology and/or process.
- To identify the parameters of interest and determine the optimal manner to implement each one's functionality.
- To develop new research instruments and procedures,
- To examine the effectiveness of current ones; To analyze measures in preparation for future study.

3.4 Programming Software

Microwave Studio's Computer Simulation Technology is one of the most effective 3D electromagnetic modeling solutions for high gain frequency components (CST MWS). CST MWS can efficiently and precisely analyze filtering, couplers, antennas, single and multilayered devices, and the impacts of electromagnetic compatibility (EMC) and electromagnetic interference (SI). As a result of its unequaled performance, CST MWS has become the go-to alternative for cutting-edge R&D laboratories throughout the globe. CST MWS, without a doubt one of the most user-friendly EM modeling tools available, presents an overview of how a high-frequency model might behave in an EM simulation.

3.5 Design technique

<u>Step 1:</u> First, utilizing the basic MPA design equations, commonly known as the equation-based antenna, components of a circular ring microstrip patch antenna (MPA) are designed to work in the 32 GHz bands.

Step 4: In the second phase, a variety of substrate materials are used to select the optimal one according to 5G requirements.

Step 3: Using a range of feeding strategies in order to zero in on the ideal one based on the current 5G criteria.

Step 4: In the process of developing antennas operating at 32 GHz including using the optimal substrate material, substrate height, and feeding mechanism.

Step 5: When ready, save both the structural and antenna simulations.

Step 6: Save the result if the antenna satisfies all of the specifications.

Step 7: Involves optimizing the built-in microstrip patch antenna to improve its performance.

Using the 32 GHz band to separate the slot with the required value.

Step 9: At this point, save both the structural and antenna simulations.

Step 10: If the antenna meets the requirements, the tenth step is to save the result.

Step 11: Evaluate the findings in light of the antennas that have previously been deployed.

3.5.1 Design of Antennas by Equation

The first stage in antenna design is to choose the proper dielectric substrate with the correct thickness (h). Di3electrics are used for variations in electrical and mechanical stability. They are used to lower the size of the antenna and aid in the generation of displacement current, which in the Magnetic Field (Ampere's Law) creates variable time. In turn, this time-varying Magnetic Field will create a time-varying Electric Field (according to Faraday's law), resulting in the formation of an electromagnetic propagating field. In this manner, the substrate may enhance the antenna's radiating capacity.

The dielectric constants of the substrates shown in the preceding table are rather high, indicating a large loss when building antennas with a high benefit. Because the objective of this research is to develop a multiband patch antenna, the Rogers RT Duroid5880 material with a dielectric constant close to 2.2 is chosen for this design. Then, it is acceptable to collect material from the microstrip line and the field. This situation has three options: Copper, Silver or Gold. Silver is more conductive than the others. Copper is far more difficult and less expensive than the other two. Thus, copper is widely used.

TABLE 3.1 LIST OF SUBSTRATES

Dielectric Name	Dielectric constant
FR4	4.4
RT Duroid-6002	2.94
RO4730	3
Rogers RO 3200	3.02
Rogers RT Duroid-5880	2.3 (used in our Design)
Rogers RT Duroid-5870	2.33
Foam	1
TLC-32	4.3

3.5.2 Equation

To calculate the antenna length and width equations (1) –(5) have been used [45]. Patch width is given by,

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (3.1)$$

where c = Velocity of Light ($3 \times 10^8\ ms^{-1}$)

The effective dielectric constant is given by,

$$\varepsilon eff = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10h}{w}\right) \qquad (3.2)$$

Where,

εeff= Effective dielectric constant,

εr= Dielectric constant of the

substrate, h = Height of dielectric

substrate, w = Width of the patch.

For a given resonance frequency fr, the effective length is given by,

$$Leff = \frac{c}{2f_r\varepsilon_{eff}} \qquad (3.3)$$

The actual length of the patch is given by,

$$L = Leff - \nabla L \quad (3.4)$$

where,

$$\nabla L = 0.412h \; \frac{(\varepsilon_r + 0.3)(\frac{w}{h} + 0.268)}{(\varepsilon_r - 0.258)(\frac{w}{h} + 0.8)} \quad (3.5)$$

The basic parameters of the rectangular microstrip patch antenna are determined in Table No 3.2 using the above equations

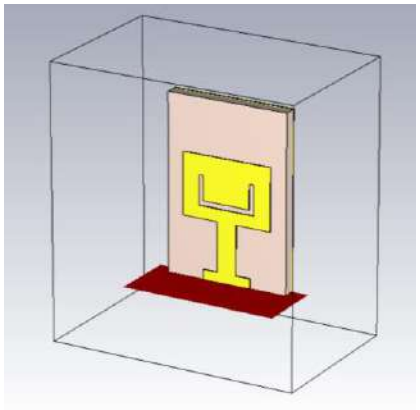

Figure 3-0-1 Equation based single element antenna

3.5.3 Optimization Via Optimizer inside CST MWS

The optimization is applied to the geometric design by employing an optimizer to boost the antenna gain after the formula-based construction of the single-element antenna. There are many algorithms that the optimizer may use. The framework of the Like-Trust Area, Genetic Algorithm, Particle Swarm Optimization, and more. These "Trust Region Framework" methods are employed in this research because they offer superior outcomes in less time. Multiple optimizations are performed to produce antennas with a higher gain than the conventional single-element antennas

Parameter	Value
Frequency (f)	32 GHz
Substrate height (h)	0.5 mm
Dielectric Constant, €	2.2 mm
Length (L)	8.935 mm
Width (W)	8.935 mm

TABLE 3. 2 Optimized Single Element Antenna Parameters

Chapter 4
Simulations and Result Analysis

In this part, the findings that were obtained after modelling the intended antenna are shown, and they are analyzed.

4.1 Simulation Results of Single Element Antenna

4.1.1 Return Loss Graph

When evaluating the performance of an antenna's transmission, the return loss, which is also referred to as the S11 parameter, is the most important factor to check. A vital piece of information on the reflected energy of an antenna may be gleaned from the return loss of the antenna. Referring to the graph that plots the S11 parameter against the frequency enables us to quickly and easily establish the operating frequency as well as the bandwidth. The value of the parameter S11, which again was dropped, fell in proportion to the degree to which the antenna's resonance increased. The frequency band is shown in the following image. Band consisting of higher frequency ranges The S11 parameter, which operates at a frequency of 46 gigahertz, may be seen shown in figure 4.1. As a consequence of the optimization, it is reasonable to infer from this graph that the resonance frequency is 46.44

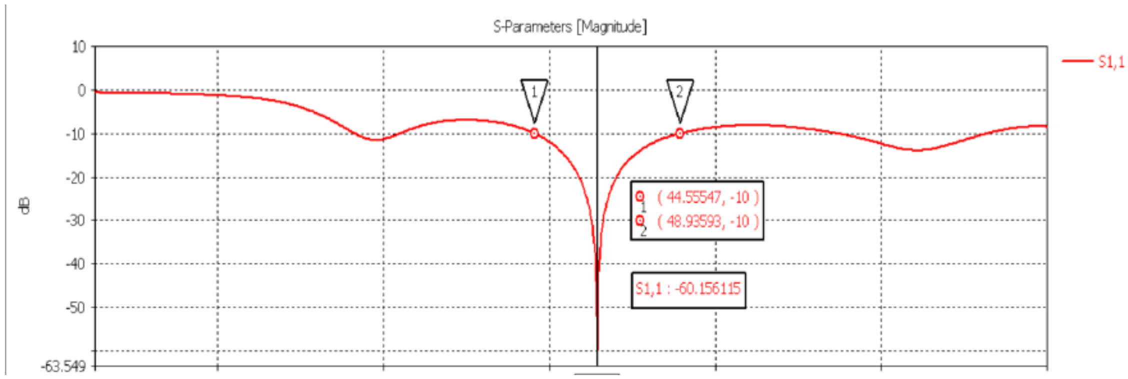

Figure 4-0-1 Equation-based single element antenna return-loss plot for 46.44 GHz

GHz, and that the value of the return loss is nearly -60 dB. These two pieces of information are consistent with the conclusion that the optimization was successful.

4.1.2 Voltage Standing Wave Ratio (VSWR)

If there is to be a successful delivery of the required quantity of power to the chosen antenna, the impedance of the transmission line and the antenna must match appropriately to a significant degree. The voltage standing wave ratio, often known as VSWR, plays a significant part in this stage. The Voltage Standing Wave Ratio, which may also be shortened to VSWR, is a metric that indicates how successfully the power of electromagnetic waves is transmitted from a particular power source into the load across a transmission line. This parameter can also be abbreviated as VSWR. The value of the voltage standing wave ratio (VSWR) may be compared to this efficiency. Consider VSWR as a variable that is equivalent to the power that is reflected by the antenna as a further method to describe it. This is one more approach to explain VSWR.

On the other hand, if the amplitude of the VSWR is low, this indicates that the antenna and the transmission system are matched, and as a consequence, the antenna receives a greater amount of power. If the amplitude of the VSWR is high, on the other hand, this indicates that there is a mismatch between the antenna and the transmission system. As a result, one may reach the conclusion that the VSWR has a greater level of quality when it is lower. At the frequency of operation of 46.44 GHz, the observed value of the voltage standing wave ratio (VSWR) for the recommended antenna type is 1.0019, which is shown in figure 4.2.

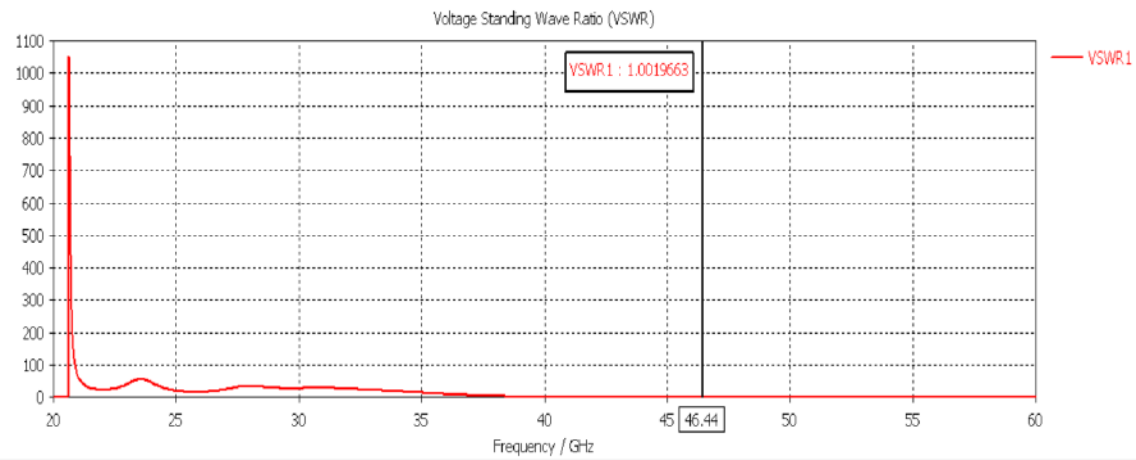

Figure 4-0-2 VSWR plot of equations based single element antenna at 46.44 GHz

4.1.3 2D Radiation Pattern

The word "radiation pattern" refers to the directionally dependent strength of the radio waves emitted by an antenna in the context of this discipline. Single-element antenna with two-dimensional radiation pattern having a satisfactory radiation pattern and a restricted beam width for the antenna that is currently being constructed. The pattern of radiation produced by a microstrip patch antenna is in the shape of a half circle, and we can see that our radiation pattern is an exact match for the standard, which is in the shape of something very close to a half circle.

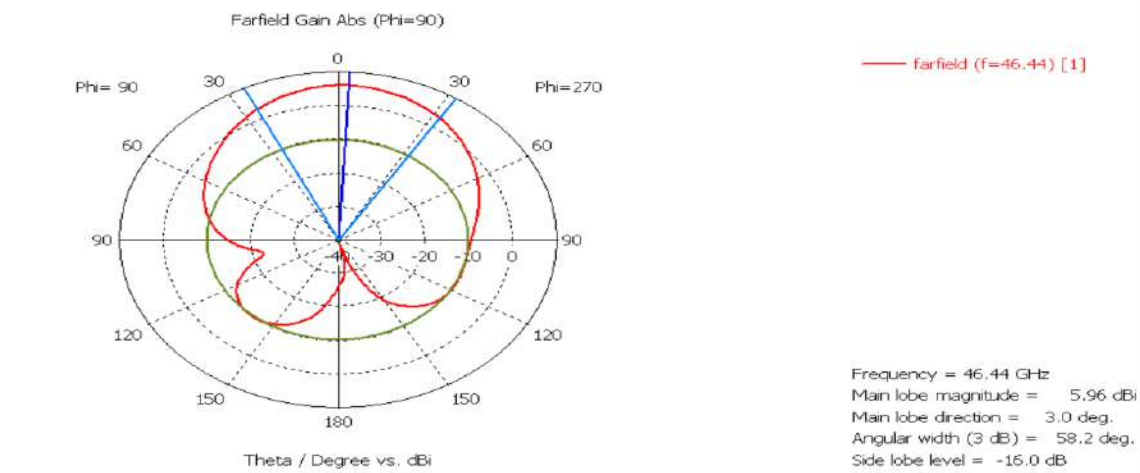

Figure 4-0-3 Single element antenna 2D radiation pattern for 46.44 GHz

4.1.4 3D Radiation Pattern

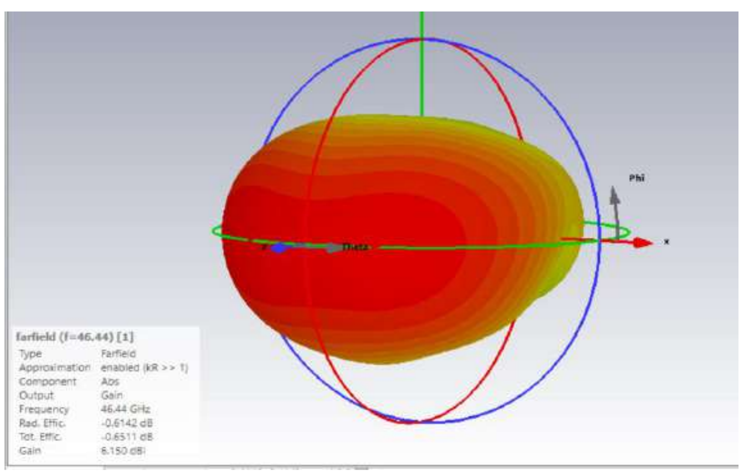

Figure 4-0-4 Single Element Antenna 3D Radiation Pattern at 46.44 GHz

An antenna that emits energy into the surrounding space using a three-dimensional radiation pattern that displays a three-dimensional image. This kind of antenna is known as a directional antenna. The far field is the name given to the 3D radiation pattern that is obtained by measuring the field when it is sufficiently far from the antenna. To put it more simply, it refers to the energy that is emitted in a particular direction by an isotropic antenna (a theoretical antenna that radiates equally in all directions). It ought to function as a decent antenna in the same way as a 2D radiation pattern. In what frequency range does it work in order to produce its 3D radiation pattern? When seen in a particular direction, the three-dimensional radiation pattern makes the given energy extremely simple to spot. The above image depicts the 3D radiation pattern at 46.44 GHz.

4.1.5 Total Efficiency

Generally, antenna effectiveness is defined as the relationship between the effective aperture area and its actual physical area. The physical aperture area is usually denoted by the percentage which defines the radio frequency (RF). Normally antenna performance of the standard value is 70 percent. Figure 4.5 demonstrate that antenna efficiency is almost 91 percent for 36.44 GHz.

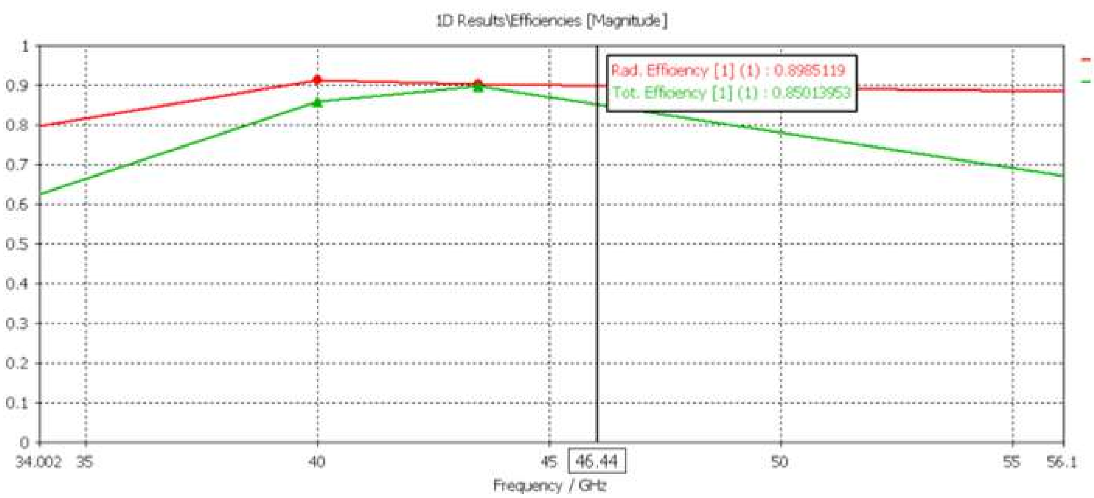

Figure 4-0-5 Total Efficiency at 46.44 GHz

4.1.6 Radiation Efficiency

The proportion of the radiated energy of the antenna is defined by the radiation efficiency. To the free space for the electrical energy received by the antenna from the feedline. The standard level of radiation efficiency is 70 percent. Figure 4.6 above seen that the radiation efficiency is 93 percent for 32 GHz.

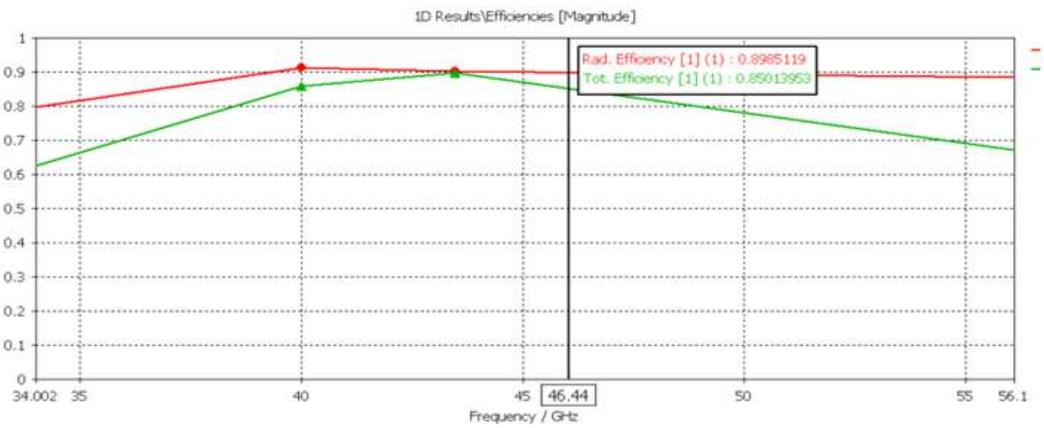

Figure 4-0-6 Radiation Efficiency at 46.44 GHz

4.1.7 Power Calculation

The power calculation in Figure 6 for 46.44 GHz demonstrates the power accepting value is 0.496 W, and the radiating power is nearly 0.44 W, which provides a loss of 0.065W. Highly efficient power is radiating nearly 90%. Fig displays power distribution for 46.44 GHz

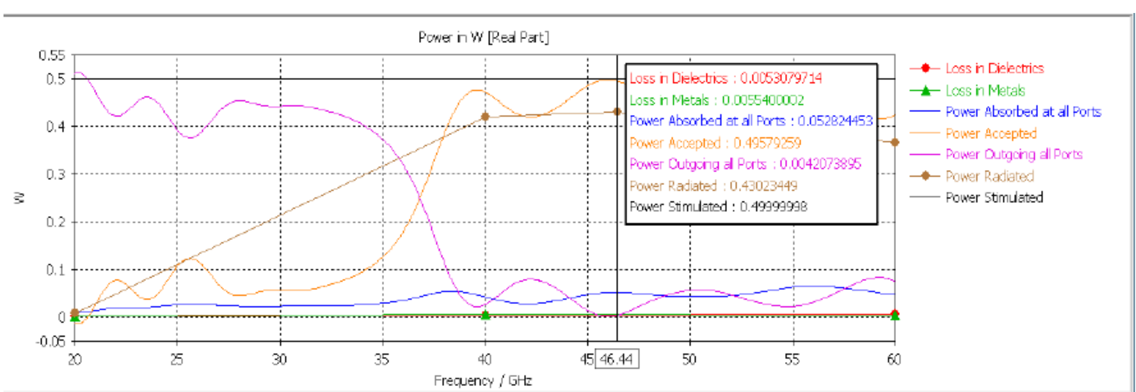

Figure 4-7 power calculation

4.2 Final Design Result of Single Element

In table 4.1, full simulation results were displayed in tabular form after optimization of the single-element antenna. This antenna design shows a good loss of return value. In comparison, the antenna's VSWR is below 1.5. And gain is also quiet compared to the recent models of an antenna. Also, this antenna's directivity is almost 6.7 dBi and the gain is 6.1 dBi which shows better directional performance. Gain 6.42 dBi at 2.6 GHz and 8.62 dBi at 28 GHz which are obtained by single element slot antenna. The antenna efficiency and radiation efficiency of this single-component antenna reach 70 and 90 percent throughout the whole band.

TABLE 4.1 Complete Simulation Result of Antenna Single Element

Parameters	**Value**	**Standard [20]**
Resonate Frequency	46.44 GHz	As per need
Bandwidth	4.5 GHz	As per need
Return loss (S_{11})	-60.156	less than -10 dB
VSWR	1.0019	2 – 1
Gain	6.1dBi	6-9 dBi
Directivity	6.7dBi	5-8 dBi
Antenna Efficiency	90%	70%

4.3 Comparison with existing single-element antennas

In the table below the designed slot antenna's performances are compared with the other recent designed slot antennas by several researchers. From those comparison results views, it can be seen that the mentioned antenna designed by the three elected parameters contented the 5G requirements better than the previous work.

TABLE 4.2 Comparison with The Single Feature Antennas

Ref. No	Resonance Frequency (GHz)	Return Loss (dB)	Gain (dBi)	Bandwidth (GHz)	Efficiency (%)
1	28	-35	4.25	8	89.6%
2	83	-55.79	7.1908	3.1195	84.13%
3	28	-40	5.1	2	87%
4	26	-24	6.8	3.23	86%
5	28.5	-32.86	7	1.632	Not mentioned
6	28	-13.48	6.63	0.847	70.18%
7	26-30	-17	7	15	60%
8	28	-40.7	5.1	2.2	87%
9	29.6 20.3	-24.3 -23.7	5.51 3.57	2.5 1	Not mentioned
10	38.54	-15.5	6.9	1.94	85%
Proposed Antenna	**46.44**	**-60.156**	**6.1**	**4.50**	**90%**

4.4 Conclusion

In this suggested antenna, a miniaturized construction is provided for use in 5G applications using mmWaves At a frequency of 46.44 GHz, the suggested antenna has a gain of 6.149 dBi and an efficiency of near 90%. Because the suggested antenna was able to be simulated accurately, it was able to get a return loss value of -60.16 and a bandwidth of 4.5 GHz. The suggested antenna is one that the ability to be considered a prospective option for future high-speed mm-wave communication systems due to its efficient performance, features and one-of-a-kind design.

Chapter 5

5.1 Achievements

A single-band patch antenna with a 50-ohm probe feed was used in the development and simulation of this antenna, which resulted in the antenna's success. The proposed antenna has a return loss that is less than -10 decibels while operating at 46.44 gigahertz. The simulated value of the voltage standing wave ratio (VSWR) is always greater than 1, with the standard value falling somewhere between 1 and 2. The whole 46.44 GHz range that completely covers the antenna bandwidth is about 4.5 GHz, as indicated by both the Federal Communications Commission (FCC) and the International Telecommunication Union (ITU). Recent years have seen the development of certain slot antennas that boast a high gain. On the other hand, some of them do not follow the rules set out by the FCC, while others are cumbersome mobile phones. As a result, antennas similar to the one proposed will be included in Smart City despite seeming futuristic. New York and Boston use 5G networks to improve garbage collection, public transportation, and crime mapping. 5G mmWave spectrum supports internet backhaul in automobiles and HD live security camera feeds in smart cities.

5.2 Limitations

The suggested antenna does not seem to have any beam-directing capabilities, which would make it possible for mobile phones to make greater use of the proposed antenna. This is substandard since the recommended antenna appears to have these capabilities.

5.3 Future Work Field

The installation of a beam steering facility, which is a beneficial addition that can be made to an antenna, may considerably enhance the coverage angle of an antenna. This is a useful addition that can be made to an antenna. In real practice, the designed and simulated antenna should be used in the environment to evaluate how well it genuinely functions. This may be done to determine how well it operates. In addition, in order to evaluate the simulation's level of accuracy, one must compare the findings of the simulation with the data obtained from other types of measurement.

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