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Performance Analysis and Comparison of 5G mm-Wave Microstrip Patch Antenna with Array

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DEDICATION

This thesis is to resolute our respected teachers and glorified parents for their support and prayers in helping us reach our goal.

CERTIFICATE OF APPROVAL

Sourav Chakraborty, bearing ID No: T181045 and Imran Hasan, bearing ID No: T181051 submitted a thesis to International Islamic University Chittagong's (IIUC) Department of Electronic and Telecommunication Engineering (ETE) entitled "Performance Analysis and Comparison of 5G mm-Wave Microstrip Patch Antenna with Array" which was approved as suitable for partial fulfillment of the requirements.

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CANDIDATES DECLARATION

It is hereby declared that the work included in this thesis has not been submitted elsewhere for the conferral of any degree or diploma and that it contains no illegitimate declarations.

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In the favor of Allah, the Gracious.We give Allah (SWT) all the honor and glory since He has provided us with a wealth of opportunities as well as kindness and guidance throughout our lives.And may Prophet Muhammad (PUBH) get Allah's blessings and peace, guiding and inspiring us in our life.We would like to convey our profound appreciation to **Md. Ariful Islam**, the supervisor of our thesis, and his co-supervisor, **Abu Zafar Md. Imran**, for their research initiative in this area and for providing helpful advice and encouragement during the study process. We thank **Engr. Syed Zahidur Rashid**, Head of the Electronics and Telecommunications Engineering Department at IIUC, for giving us the best departmental resources and for his prompt recommendations. Additionally, we are appreciative of **Engr. Abdul Gafur** commitment and effort as our thesis' convener. We also want to thank all of our instructors for their dedication and hard work over the course of our academic careers.And we are grateful to our parents for their assistance throughout our life thus far. Additionally, we would like to thank our friends for helping us finish this thesis, whether directly or indirectly.

ABSTRACT

A microstrip patch antenna that can operate in the 5G mm wave band with a return loss of -67dB, gain of 7.6 dBi, and coverage of the resonating frequency of 28 GHz is demonstrated in this study. In CST Studio Suite, a 2×2 and a 4×4 array antenna have been created with the same form factor as the patch. This paper also compares the performance of a microstrip patch antenna to an identical array antenna. All of the simulated designs used the substrate Rogers RT 5880, which has a dielectric constant of 2.2. This is extremely useful in contemporary devices due to its small antenna design. Additionally, the gain of the proposed microstrip antenna is 7.6 dBi as opposed to the 13.07 and 15.5 dBi gains of the array antennas simulated results. The antenna has two circular parasitic elements and two slots in the patch, which have a great impact on how well it performs.

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LIST OF SYMBOLS

Hertz	Hz
Kilo Hertz	KHz
Mega Hertz	MHz
Giga Hertz	GHz
Millimeter	mm
Meter	m
Relative permittivity	ε
Length	L
Width	W
Decibel	dB
Dielectric Constant	εr

LIST OF ABBREVIATIONS

RT	Duroid 5880
MPA	Microstrip Patch Antenna
FSE	Faculty of Science and Engineering
ETE	Electronic and Telecommunication Engineering
IIUC	International Islamic University Chittagong
IEEE	Institute of Electrical and Electronic Engineers
LTE	Long Term Evolution
FCC	Federal Communication Commission
GSM	Global System for Mobile communication
CST	Computer Simulator Technology
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
MICs	Microwave integrated circuits
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
GPRS	General Packet Radio Service
MIMO	Multiple Input Multiple Outputs

Chapter 1
Introduction

1.1 Evolution of wireless communication

Wireless communication is the transport of information between two or more sites without the need of an electrical wire, fiber optic, or other continuous controlled medium. Radio signals are used in the majority of wireless communication. Intentional distances through radio waves can range from a few meters for Wireless to millions of miles for deep-space radio transmissions. With continuous advancements and growth in the mobile and telecommunications sectors, one of the finest technologies ever developed has proven to be the advancement of generation bands. The first step was the 1G mobile network., which communicated only analog communications, and was followed by the 2G mobile technology, which transmitted digital signals. After 1G and 2G mobile technologies, 3G, or third generation technology, was introduced. Its successor, 3G, featured faster data transfer speeds than 2G. Long Term Evolution (LTE) is the name given to the fourth generation of mobile technology (4G) (LTE). Many services were incorporated into 4G, including entertainment, multimedia, mobile apps, and many more. The foundations for 5G mobile technologies (OTP) were OWA (Open Wireless Architecture) and Open Transport Protocol. The evaluation of wireless communication in now zero generation to fifth generation

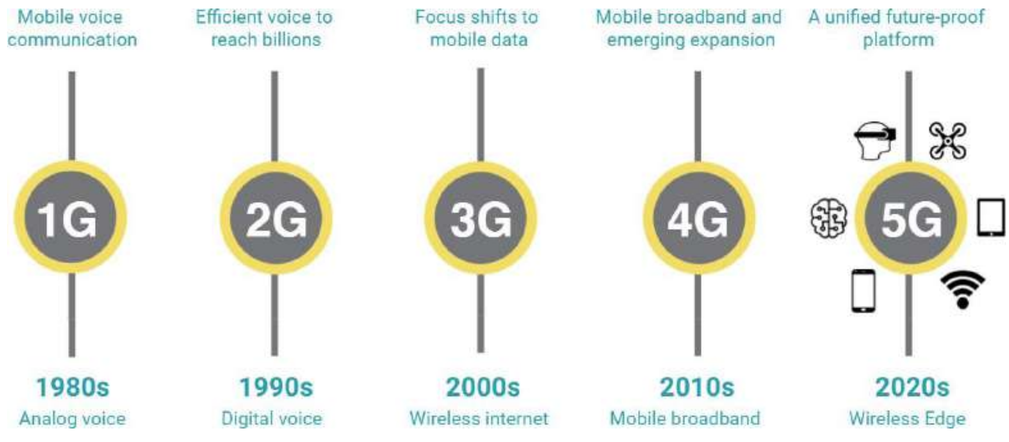

Figure 1.1: Evolution of communication [1]

1.2 Technology of the zero generation

The OG (Zero Generation) process is commonly referred to as the Mobile Radio Telephone system. Because this generation existed before the cellular system, it was referred to as precellular system. This system was asynchronous, which meant that analog signals served as carriers. The evolution of communication begins with traditional mobile telephony, in which PTT (Push to Talk) enables half-duplex communication, MTS (Mobile Telephone Service-1946-USA), and an advanced variation of MTS, IMTS (Improved Mobile Telephone System), which offers a full duplex system. Another technology used to increase customer communication is AMTS (Advanced Mobile Telephone System). In the communications world, these are all first-stage technologies that are termed 0G.

1.3 Technology of the first generation – 1G

The first generation of mobile wireless communication technology is referred to as 1G. Mobile telecommunications development began in the 1980s and was finished in the early 1990s. The first cellular system was unveiled in 1979 by Tokyo, Japan-based Nippon Telephone and Telegraph (NTT). Nordic Mobile Telephone (NMT) and (TACS) were two of Europe's most widely used analog systems in the 1980s. Other analog systems were also introduced throughout Europe. It used voice services and was based on the Advanced Mobile Phone System (AMPS) technology. The AMPS system utilized frequency division multiple access and was frequency modulated with a data rate of 30 kHz and a waveband of 824-894 MHz (FDMA) [2].

1.3.1 Features of 1G

- Frequencies of 800 and 900 MHz
- 10 MHz bandwidth (666 duplex channels with bandwidth of 30 KHz)
- Analogue switching technology
- Frequency Modulation (FM)
- Voice-only mode of service
- Frequency Division Multiple Access is an access method (FDMA)

1.4 Technology of second generation – 2G

The NFAP allocates spectrum in the 900 MHz and 1800 MHz bands for second generation mobile services. Currently, five carriers provide this GSM-based second-generation mobile service. Among them, Airtel offers 2G service in the ITU-designated E-GSM band (900 MHz) [3]. The main objective of this generation was to establish a secure and dependable communication route. With the transition from 1G to 2G technology, the introduction of many of the essential services we still use today, such as SMS, internal roaming, conference calls, call hold, and service-based pricing, internal roaming, conference calls, call hold, and service-based pricing, including long-distance call rates and real-time billing.

1.4.1 Features of 2G

- The digital system (switching)
- SMS services are available.
- It is possible to roaming.
- Increased security through encrypted voice communication
- The first internet connection with a lower data rate
- Low data rate is one of the disadvantages of the 2G technology.
- Mobility issues
- Mobile devices have less functionality.
- Limited user base and hardware capabilities

1.5 Technology of third generation – 3G

3G technologies are based on CDMA and TDMA. Utilizing services like mobile television, GPS (global positioning system), live streaming, and video conferencing are examples of third generation technology (3G) technologies. Rapid data transfer rates are the main feature of 3G networks (Third Generation Technology). In order to employ broadband technology, the ITU sells multiple frequency rates. Users trust network authentication because it allows them to rely on their network as a trustworthy source of data transport. Because it can handle all five major radio technologies, 3G technology is far more adaptable. These radio systems employ FDMA, TDMA, and CDMA.IMT-DS (direct spread) and IMT-MC are compatible with CDMA (multi carrier). TDMA manages both IMT-TC (time code) and IMT-SC (single carrier). There is just one radio interface in FDMA, known as IMT-FC or frequency code. Because of industry collaboration, third-generation technology is now truly inexpensive. This arrangement moved quickly in order to encourage user adoption. This technology is based on fully wireless internet connectivity. The WiMAX name was created in 2001 by the WiMAX forum. This technique eliminates the need for cables and is capable of providing 10 mbits/sec. It has the ability to connect you to a hotspot.

1.5.1 Features of 3G

- Increased data rate

- Video chat
- Increased security, user count, and coverage
- App support
- Multimedia message support
- Maps and monitoring of location
- Better web surfing and TV streaming
- High-quality FPS 3D games

1.6 Technology of four generation – 4G

It is essentially an expanded version of the previous 3G technology, with greater capacity and features than its all predecessor. From the consumer's perspective, although carriers feel justified in using the 4G moniker since it lets the user know that rapid data transfer speeds may be expected, 4G is more of a digital marketing term than a technical standard. With 4G, high-quality end-to-end Internet Protocol audio and video streaming is anticipated. Long Term Evolution (LTE), often known as 4G, will be capable of providing 150Mbps download rates for mobile users and 1Gbps download rates for stationary customers. Though the exact meaning is unknown, we may state that "4G is the fourth generation of wireless technology, enabling mobile multimedia anytime and everywhere, with worldwide support and integrated personalized personal service." Rate-adaptive coding techniques that use channel information from measured parameters or input from the Mobile Terminal (MT) can be used in 4G networks. To reduce the overhead associated with retransmission, a Hybrid ARQ method can be implemented. To boost data speeds further, space time codes and various antenna systems such as smart antennas can be employed.

1.6.1 Features of 4G

- Support for real time interactive media, audio and video streaming, FPS gaming, fast internet, and other popular broadband services.
- IP-based modern mobile communication system
- Great speed with very large capacity, and cheap cost per bit.
- Mobile service globalization, service portability, and scalability
- Avoidance of traffic congestion.
- A seamless fast network of several protocols. Because 4G will be completely IP, it will be interoperable with all commonly used network technologies.

- Infrastructure to support existing 3G systems as well as other analog wireless technologies. [4]

1.7 Technology of five generation – 5G

Clusters, which are relatively tiny geographic units used in 5G networks, are divided up into the service area. Fixed antennas on distributed frequency channels assigned by the main cellular base station are used by all 5G wireless devices connected in a cell to establish a radio connection with the main base station. The base stations, often referred to as nodes, are all connected high-bandwidth optical fiber can be used to connect switching centers in the telephone network and internet routers, or wireless backhaul lines. Network architecture will progress thanks to 5G technologies.

The 5G New Radio standard will employ spectrums not currently used by 4G to create a more robust 5G wireless air interface. Massive MIMO (multiple input and multiple output) technology will be used in newly developed antennas to allow many transmitters and receivers to convey more data simultaneously. The new radio spectrum is not the only place where 5G technology may be used. A convergent, heterogeneous network using both licensed and unlicensed wireless technologies is what it aims to deliver. As a result, users will have access to more bandwidth. The 5G architectures will be software-defined platforms, where software rather than hardware will be used to control networking capabilities. The 5G architecture may be dynamic and adaptable and offer anytime, everywhere user access thanks to developments in virtualization and also cloud-based technologies, IT, and business processing automation. Network slices are software-defined visual depiction for possible 5G network designs. With the help of these slices, network administrators may specify how users and devices should interact with the network [5]. A further way that 5G enhances digital experiences is through automation made possible by machine learning (ML). 5G networks must use automation via Machine Learning and, eventually moving towards deep learning and also artificial intelligence to achieve response times which is fractions of a single second (example: those necessary for self-driving cars) (AI).

Provisioning automatically and proactively will save traffic and service costs while enhancing the connected experience. In certain developed parts of the world, 5G service is already available. The term "5G non-standalone" is used to describe these first-generation automated 5G services (5G NSA). This 5G radio enhances the design of the current 4G LTE network.

4G LTE will be outperformed by 5G NSA. Though 5G standalone is the industry's primary target for fast, low-latency 5G technology (5G SA). It should be widely accessible by 2020 and 2022, respectively. In addition to ushering in a new era of faster networks, 5G technology will also bring in new connected experiences for customers. Thanks to 5G technology and Wi-Fi 6 connections, patients will be monitored via linked gadgets that continuously upload data on crucial health tracking signs like heart rate and high blood pressure. Future 5G networks paired with ML-driven complicated algorithms will be used in the automobile sector to offer information on traffic, accidents, and more. Cars will be able to interact with other vehicles and with objects on the road, such as traffic lights, with ease. The only two commercial applications of 5G technology which will provide customers a better, safer experience are these two.

1.7.1 Features of 5G

- Upto 10Gbps data transfer rate – 10 to 100x times faster than 4G and updated 4.5G networks.
- Latency of one millisecond
- 1000 times the bandwidth will be provided per unit area
- The number of total connected devices with one unit area may be increased up to 100x (compared with 4G LTE)
- 99.999% uptime is generally expected.
- Full coverage
- 90% decrease in network energy use.

Every generation has, in some way, improved upon the one before it. When comparing cell networks, there is a lot of ground to cover. Below is a comparison table of 2G, 3G, 4G, and 5G. The comparison those technologies makes the distinctions between the technologies very evident. The comparison of the mobile network technologies 2G, 3G, 4G, and 5G also shows that the latter will represent one of the most ambitious developments ever.

Table 1.1: Comparison generation of wireless communication technology [6]

Comparison	2G	3G	4G	5G
Introduced in year	1993	2001	2009	2018
Technology	GSM	WCDMA	LTE, WiMAX	MIMO, mm Waves

Access system	TDMA,CDMA	CDMA	CDMA	OFDM, BDMA
Switching type	Circuit switching for voice and packet switching for data	Packet switching except for air interface	Packet switching	Packet switching
Internet service	Narrowband	Broadband	Ultra band	Wireless World Wide Web
Bandwidth	25 MHz	25 MHz	100 MHz	30-300 GHz
Advantage	Multimedia features (SMS, MMS) internet access and SIM introduced.	High security, International roaming.	High speed handoffs, global mobility.	Extremely high speed, low latency.
Application	Voice calls, short messages	Video call, mobile TV, GPS	Hight speed application, mobile TV, wearable devices.	Hight resolution video streaming, robots and medical procedure.

1.8 The global 5G spectrum

	<1 GHz	3GHz	4GHz	5 GHz	24–28 GHz	37–40 GHz	64–71GHz
	600 MHz	3.5GHz		5.9–7.1GHz	27.5–28.35GHz	37–37.6GHz	64–71GHz
	600 MHz	3.5GHz		5.9–7.1GHz	27.5–28.35GHz	37.6–40GHz	64–71GHz
	700 MHz	3.4–3.8GHz		5.9–6.4GHz	24.5–27.5GHz	37–37.6GHz	
		3.4–3.8GHz			26, 28GHz	37–40GHz	
		3.4–3.7GHz			26, 28GHz		
		3.46–3.8GHz			26GHz		
		3.6–3.8GHz					
		3.3–3.6GHz			24.5–27.5GHz	37.5–42.5GHz	
		3.4–3.7GHz	4.8–5GHz		26.5–29.5GHz		
		3.6–4.2GHz			27.5–29.5GHz		
		3.4–3.7GHz	4.4–4.9GHz		28 GHz	39GHz	

Figure 1.2: Global 5G spectrum [7]

1.9 The FCC is driving key spectrum initiatives to enable 5G

Across the low-band along with mid-band, and high-band, including all mmWave

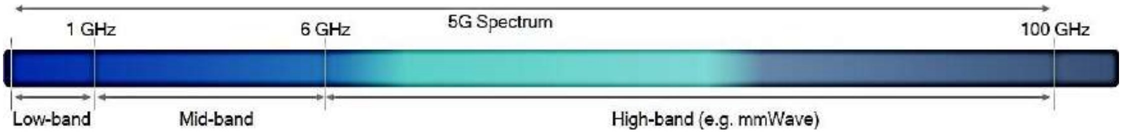

Figure 1.3: Spectrum for 5G [8]

1.9.1 Low-band

Public auction for the Broadcast Incentive

- After the assignment phase, a piece of the 600 MHz spectrum was successfully auctioned off, generating $19.8 billion in profits.
- Includes 70 MHz of licensed spectrum (2 x 35 MHz) and 14 MHz for all the unlicensed usage.
- The FCC set aside 2 x 3 MHz at 900 MHz for using broadband, mostly for utilities.
- Spectrum availability is timed to coincide with 5G. [9]

1.9.2 Mid-band

Residents' access to broadband radio

- 150 MHz in the 3.5 GHz range were opened up for sharing with all incumbents, PAL 2 and GAA 3.
- The FCC allowed early GAA installations in September 2019, and the PAL auction was concluded in September 2020.
- The FCC awarded 3.7, 4.0 GHz in March 2020. The auction is set for December 2020.
- The FCC issued NPRMs for 3.45, 3.55 GHz and 4.94 4.99 GHz in September 2020. The auction of the following 3.45, 3.55 GHz is scheduled for December 2021.
- The NTIA along with FCC are looking towards repurposing 3.1, 3.45 GHz for commercial usage. [9]

1.9.3 High-band

Three mm Wave auctions have been finished by the FCC, most recently the biggest auction ever.

- 70% of the now available spectrum is shared or till now unlicensed, according to the FCC's allocation of 10.85 GHz in many mm Wave licensed bands in 2016.
- The FCC has taken a second order to distribute 24.25, 24.45, 24.75, 25.25, and 47.2, 48.2 GHz in November 2017.
- The FCC suggested in June 2018 making 25.25, 27.5 and 42.5 GHz available for flexible wireless usage.

- In the bands of 28 and 24, the FCC has undertaken auctions.
- The auction for the higher 37, 39, and 47 GHz bands was finished by the FCC in March 2020.
- In addition to opening spectrum above 95 GHz, the FCC is proposing guidelines for the 70, 80, and 90 GHz bands. [9]

1.10 Antenna basics

A metal conductor known as an antenna is used to transmit radio frequency (RF) waves between two locations in space. Signals can be sent or received by this device. When a transmitting antenna receives a voltage, it produces radio waves that go to a receiving antenna and are converted back into electrical energy in the form of information. Radio waves interact with antennas as they travel across space from one spot to another. These components have been around for a while and are utilized in many electronic systems, including radar, radio, and television, that need signal transmission by electromagnetic waves.

1.10.1 Antenna frequency

The frequency of an antenna is defined as the number of wave cycles per second. The frequency unit of measurement is Hertz (Hz), and one Hz equals one cycle (oscillation) per second. The wave in the Figure 1.4 below oscillates three times per second, hence the frequency is three hertz.

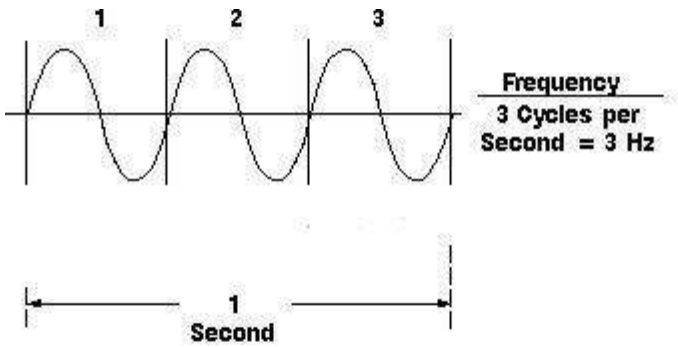

Figure 1.4: Diagram of wave frequency [10]

1.10.2 Bandwidth

The term bandwidth refers to the exact rate of data flow. It is the quantity of data that can be transported between two data points in a given time period. Bandwidth is also an important term in many other technical disciplines. It is commonly used in signal processing to define the difference between the higher and lower frequencies in a transmission, such as a radio signal, and is normally measured in hertz (Hz). The maximum amount of data that may be transmitted via an internet connection far specific duration of time. The quantity of data which can be transferred across a connection in a specific duration of time which measured in megabits per second, is what is sometimes misunderstood with internet speed (Mbps). For instance, the majority of antenna types have incredibly small bandwidths which cannot be easily used for a wideband operation. The bandwidth is frequently described in terms of its fractional bandwidth (FBW). The ratio of the total frequency range to the center frequency is known as the FBW. The Q antenna and bandwidth are related concepts.

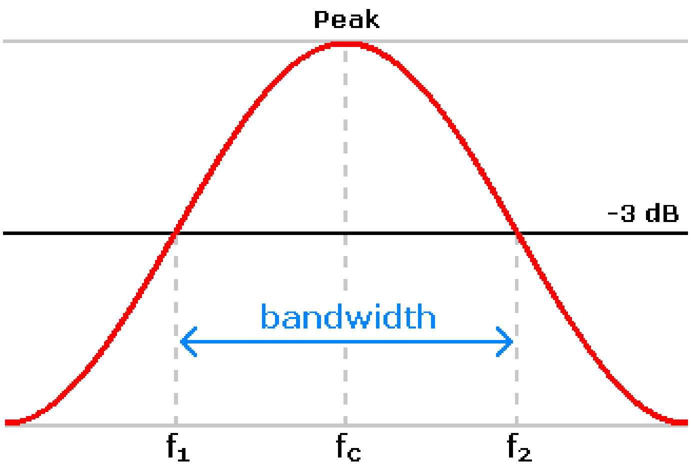

Figure 1.5: Bandwidth [11]

1.10.3 Input impedance

The input impedance is essential because it dictates how much load the filter presents to the circuit running the filter. The exact value of input impedance varies greatly with the frequency. The input impedance approaches that of a conventional voltage follower amplifier at extremely low frequencies. The input impedance reduces as the input frequency increases.

1.10.4 Impedance matching

The process of adjusting an electromagnetic load's output and input impedances to reduce signal reflection or improve power transmission is known as impedance matching. A source of power, like an amplifier or generator, and an electrical load with a source impedance, such a light bulb or a transmission line, in an electrical circuit. This exact source impedance is comparable to series resistance and reactance. Maximum power is transferred from the source to the load whenever the load resistance is equal to the source resistance and the load reactance is equal to the source reactance's negative, according to the well-known maximum power transfer theorem. It means that the greatest power may be delivered if the load impedance is precisely equal to the complex conjugate of the input impedance [12]. The frequency is not regarded in the DC circuit. As a result, if the main load resistance matches the source resistance, the condition is met. The reactance of an alternating current circuit is frequency dependent. As a result, matching impedance for one frequency may not truly matched as the frequency is altered.

1.10.5 Directivity and gain

The form of the radiation pattern of the antenna under test is compared to a reference radiation pattern to determine directivity. Most frequently, the reference would be the isotropic model's flawless spherical pattern stated above. This measurement is in decibels relative to isotropy, or dBi. A dipole antenna is also used as a reference, and the quantities are specified in dBd (meaning decibels relative to dipole). Gain is a difficult specification to understand. There is a big difference between the overall gain of an amplifier and the gain of an antenna. As an active device, the amplifier injects energy into the system. Because an antenna cannot produce energy, it is a passive device. Gain is sometimes misunderstood incorrectly as an increase in output power over unity. Of fact, this is not conceivable since the radiated power would be more than the power put into the an

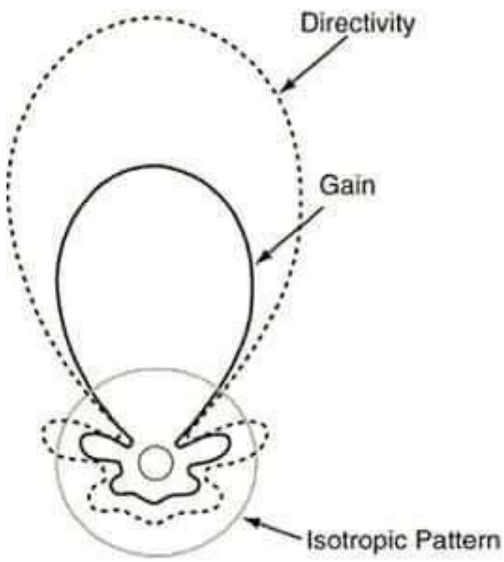

Figure 1.6: Diagram of directivity and gain [13]

1.10.6 Radiation pattern

It generally indicates to the geometrical solid positioning in space that contains all of the antenna's lobes. It is a receiving antenna's response to a uniformly intense signal originating from all directions. A single antenna's transmitting and receiving radiation patterns are identical. There are two sorts of radiation patterns to consider: 1) The wavelength, feed mechanism, and reflector qualities determine the free space radiation characteristics, which is the entire lobe structure of the antenna. 2) The field radiation pattern, as seen in the majority of surface-based radars, which deviates from the free space pattern mostly due to the formation of interference lobes when straight and reflected wave trains interact. The main envelope of these interference lobes(beam) has the same form as the free-space radiation pattern, but it has up to double the amplitude for a flawlessly reflecting surface.

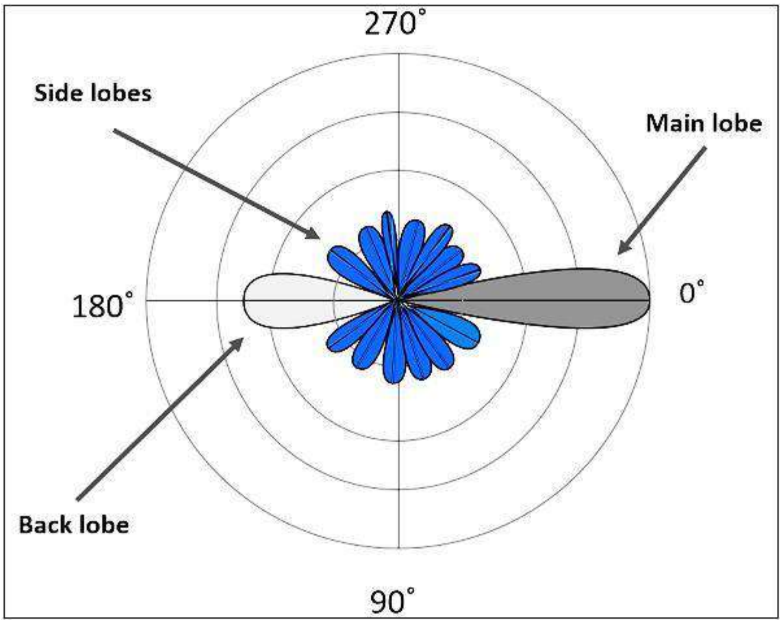

Figure 1.7: Diagram of radiation pattern [14]

1.10.7 Reflection Coefficient

Return loss is the term used to describe the power loss experienced by a signal when it is returned by a discontinuity in a transmission line or optical fiber. Decibels are commonly used to quantify this. In other words, there will be an infinite loss of return if all the power is communicated to the load. In contrast, there is no return loss and full power is restored if there is an open circuit or short circuit termination. S11 is the most widely used antenna parameter in practice. In reality, S11 is nothing more than a return loss (RL). If S11=0 dB, all forces are reflected in the antenna and no radiation occurs. If the antenna receives 3 dB of energy and S11= -10 dB, the reflected energy is -7 db. A -9.5 dB or lower RL or S11 VSWR is acceptable in the upper two bands. A RL of -10 dB is judged acceptable in this thesis [15].

1.10.8 Voltage Standing Wave Ratio (VSWR)

Voltage standing wave ratio (VSWR) is the ratio of transmitted to reflected voltage standing waves in an RF electrical transmission system. It measures the efficiency of RF power transfer from the primary power source to the load through a transmission line. A power amplifier that is linked to an antenna through the main transmission line serves as a typical illustration. SWR stands for the ratio of transmitted to reflected waves. A high SWR is a sign of inefficient transmission lines and reflected radiation, which can harm the transmitter and reduce its efficiency. Since it is usually used to refer to the voltage ratio, SWR is also commonly known as voltage standing wave ratio (VSWR).

1.10.9 Polarization

The polarization of an antenna might be linear, circular, or elliptical. When an antenna transmits radio frequency (RF) radiation in a single plane that is either horizontal, vertical, or at an angle between the two with respect to the Earth's surface (Figure 1.8), it is said to be linearly polarized. Vertically polarized antennas transmit energy perpendicular to the Earth's surface, whereas horizontally polarized antennas do the opposite. Theoretically, circular polarization is defined as a linear combination of equal amplitude, 90° out-of-phase horizontal and vertical waves. The horizontal and vertical planes as well as any in-between planes are all included in this, which is comparable to a wave rotating in time at a constant rate that is either left-hand or right-hand polarized (i.e. spinning in opposite directions).

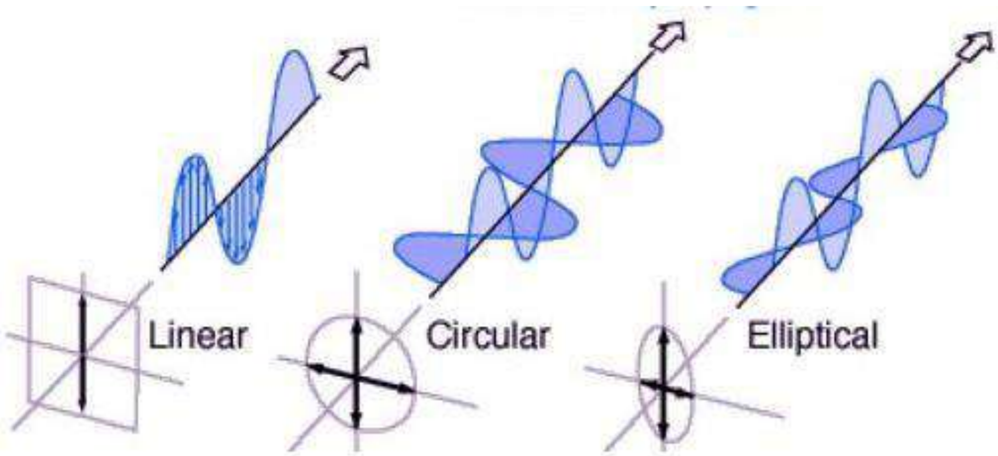

Figure 1.8: Polarization Liner, Circular and Elliptical [16]

The third most prevalent kind of polarization is elliptical polarization, which is a generalization of circular polarization. It occurs when the two linear or straight perpendicular components of the electric field are both 90 degrees out of phase while having differing magnitudes.

1.11 Antenna array

An antenna array is a group of connected antennas arranged in a predictable fashion to create a single antenna that can produce radiation patterns that separate antennas cannot. Antenna arrays are assemblages of electromagnetic energy and frequency radiators that are isotropic. They lessen the difficulties brought on by single antennas. For instance, a dipole antenna offers better direction control than an isotropic antenna, although control direction may decrease as dipole length increases. A system with several radiators offers more control and flexibility over the beam's direction.

1.12 Microstrip patch antenna

A microwave radiating or receiving element is characterized as a microstrip patch antenna. It consists mostly of a metallic copper patch created on top of a solid dielectric substrate with a ground plane. Because of its numerous advantages, this form of antenna is gaining popularity. Patch antennas generally come in a variety of configurations, including various shapes. In recent years, all of these variants have been thoroughly scrutinized. There are also several feeding techniques. The manner of feeding an antenna can be advantageous in terms of maximizing the antenna's overall performance, including return loss and radiation patterns. In figure 1.9 depicts the construction of a microstrip patch antenna, which has a ground plane on one side and a radiating patch on the other on a dielectric substrate. The patch can assume any form and is typically composed of various conductive metals like copper and gold. Normally, feed lines and the radiating patch are installed on the dielectric substrate surface. The patch typically has a regular form like a square, rectangle, circle, triangle, ellipse, novel, or any other shape to aid analysis and performance prediction. The microstrip patch antennas emit due to fringing fields between the patch edge and the ground plane.

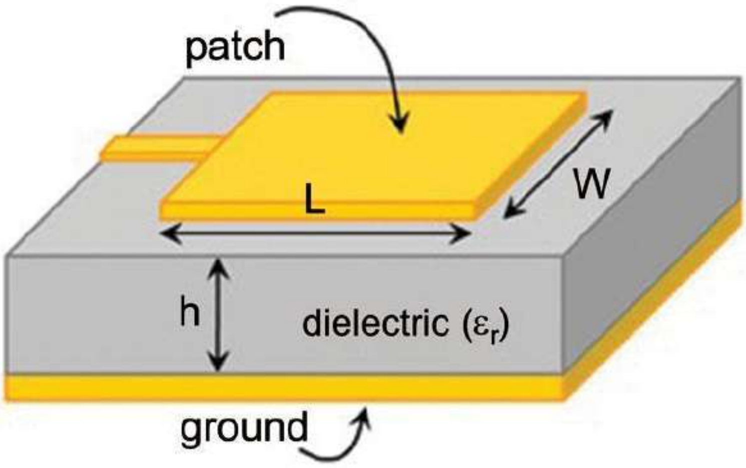

Figure 1.9: Structure of microstrip patch antenna [17]

1.12.1 Advantage of microstrip patch antenna

- Maintain a low profile.
- Low cost.
- Linear and circular polarization are also possible.
- Dual band and also dual polarization are options.
- No cavity support is required.
- Easily integrated with microwave IC.

1.12.2 Disadvantage of microstrip patch antenna

- Limited bandwidth.
- Power handling is limited.
- Gain is little.
- It is difficult to attain polarization purity.
- End-fire radiation is poor.
- Extraneous radiation emitted by the feed.

1.13 Microstrip antenna feed technique

There are several feeding mechanisms for microstrip patch antennas. There are only a handful popular or commonly applied feed techniques:

- Microstrip line feed
- Coaxial probe feed
- Aperture coupling feed
- Proximity coupling feed

1.13.1 Microstrip line feed

This is a feeding method. As demonstrated in Figure 1.10 below, a metallic constructed Directly linked to one edge of the planned Microstrip patch is the microstrip feed. The main benefit of this technique is that the patch and feed are on the same plane, making fabrication easier.

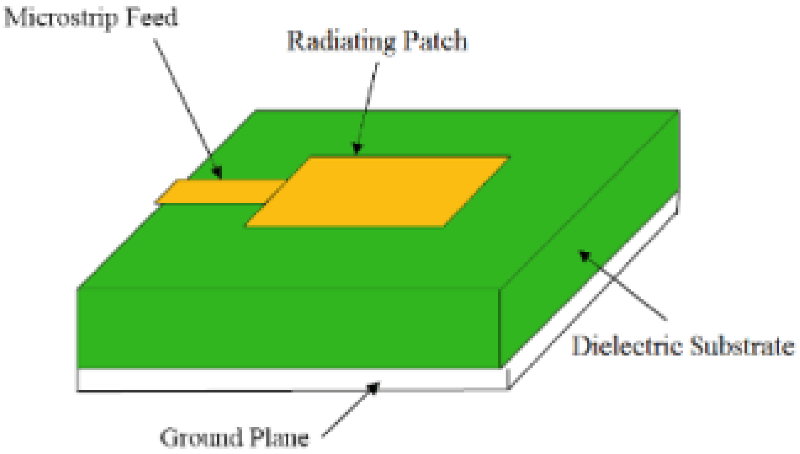

Figure 1.10: Microstrip line feed [18]

1.13.2 Coaxial probe feed

This is a popular feed mechanism seen in microstrip patch antennas. For feeding, a coaxial connection is employed in this procedure. The coaxial connector's center conductor wire is directly attached to the main radiating patch, while the other outside half of on the ground plane, the conductor has been soldered. The advantage of this feeding strategy is that the feed point may be placed wherever it is most compatible with the radiating patch's input impedance.

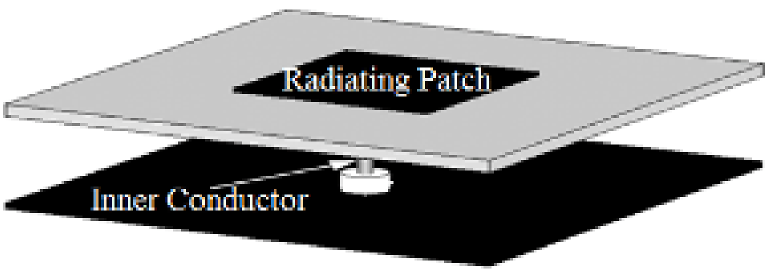

Figure 1.11: Coaxial probe feed [18]

1.13.3 Aperture coupling feed

Another feeding strategy places the ground plane between the feed line and the primary radiating patch. Between the feed line and the microstrip patch, there is a slot that connects them. This approach is rarely utilized due to the difficulty of fabricating numerous layers, which increases antenna thickness.

Figure 1.12: Aperture coupling feed [18]

1.13.4 Proximity coupling feed

This method is referred to as the electromagnetic coupling technique. This method places the feed line in the middle dielectric substrates and places the radiating patch on top of the upper substrate.

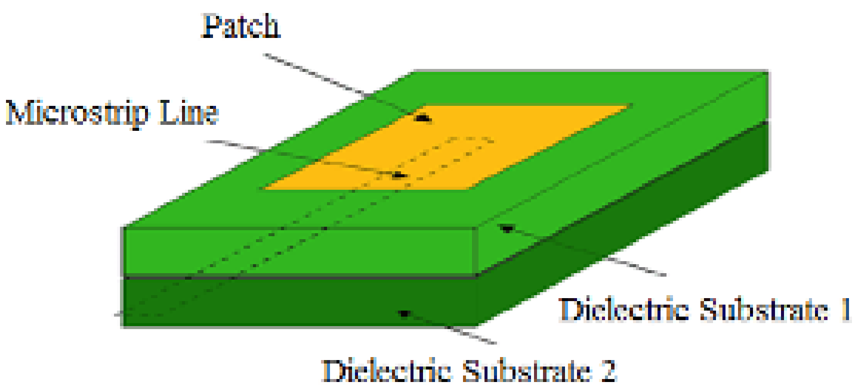

Figure 1.13: Proximity coupling feed [18]

1.14 Design Tool

1.14.1 CST Microwave Studio

A complete software package for high-frequency electromagnetic analysis and design is CST Microwave Studio. By offering a thorough solid modeling front end constructed on the

ACIS modeling kernel, it simplifies the structure input procedure. The definition of your device is substantially simplified by strong graphic feedback.

Before beginning the simulation engine, a completely automated meshing process is performed after the component has been modeled. CST MICROWAVE STUDIO is a high-quality equipment for high-frequency electromagnetic 3D simulation. CST MWS enables the user to assess high frequency elements such as antennas, microwave device, filters, couplers, planar and multi-layer models, and the effects of SI and EMC in real time. The program includes both time domain and frequency domain solvers. CST is responsible for extra solver modules for specialized applications. Specific CAD file import filters and SPICE parameter extraction enhance design choices and save time. For electromagnetic design and analysis, CST offers accurate, effective computer solutions. This user-friendly 3D EM modeling technology allows one to select the best approach for modeling and automating equipment at a wide variety of frequencies.

1.15 Motivation

Since its inception, wireless communication has been more and more popular due to its low cost, adaptability, portability, and other advantages. As a result, there has been a fast growth in demand for mobile connections and data rates. Mobile data traffic has increased significantly during the last four decades. The Internet of Things has once again increased the scope of these requirements. To meet this growing need, the telecom industry has generated new generations of standards nearly every decade. They have resulted in the fifth generation (5G), which will be deployed in the early 2020s in order to achieve the goals of linking more than a 100 billion wireless devices, with millisecond latency, 10 Gbps data speed, and the internet of things. [19] One of the main challenges for the implementation of 5G is path-loss at high frequencies, therefore we created an antenna that can handle it.

1.16 Essence

5G will meet the need for 1,000-times traffic growth in a sustainable manner. The user experience on 5G will have "zero" latency and an access data rate similar to that of fiber. The 100 billion gadgets that 5G will be able to link will be able to provide a consistent experience in a range of situations, such as those with exceptionally high mobility, connection density, and traffic volume. The 5G goal of "information a finger away, everything in touch" will be realized by all of us thanks to 5G's offering adaptive optimization dependent on the user's awareness of the services, mostly to boost energy and cost effectiveness by over a hundred times. Mobile wireless technology has undergone a massive revolution in the last few decades, accompanied by several generations of communication. Because of its high popularity and wide range of bands, including sub-6GHz and mm-wave, 5G has become a massively popular source of research. As we progress towards modern technology, we will require a much higher data rate and bandwidth to meet our growing demands. This is where the mm wave comes into play, as it provides a comparatively high data rate. This microstrip patch antenna is primarily designed at 28 GHz to meet this requirement. In 5G communication System 3GPP Release-15 Covers the resonating frequency of 28 GHz [19]. One of the drawbacks of Microstrip antenna in mm wave is it has a comparatively low bandwidth and poor gain. To overcome this issue in 5G communication System a 2×2 and a 4×4 array antenna with a good return loss and better gain is designed.

Chapter 02
Literature Review

2.1 Paper Review

This chapter will discuss the works of other authors associated with the study "Performance Analysis of mm Wave 5G Microstrip Patch Antenna," which is crucial for successful mobile application testing with the current antenna for the fifth generation (5G). For a better performing and easier to manufacture antenna model and simulator.

1. **For 5G wireless applications, a 28 GHz compact microstrip patch antenna**

This article describes a small planar inset-fed microstrip antenna that used with a mm wave system for 5G wireless communications (28 GHz). The CST Studio is used to optimize the antenna parameters. At 28 GHz frequency, simulated Reflection Coefficient plot, far-field radiation pattern, efficiency and gain are achieved. The simulation's output was compatible with 3GPP Release-15 for 5G wireless applications operating in the 28 GHz frequency band. According to the simulated results, the antenna has the least amount of reflection at 28 GHz and a return loss of -17.4 dB, an antenna gain of 6.72 dB, and a voltage standing wave ratio of 2 (VSWR) [20].

2. **A Novel Microstrip Antenna Based on mm Wave Defected Ground Structure for 5G Cellular Applications**

For the upcoming fifth generation (5G) of mobile communication, a high-performance, dual-band, circular patch microstrip antenna is proposed. The ground plane of the designed antenna contains a Defected Ground Structure (DGS) in the form of a ring. The proposed antenna operates at the proposed 5G frequency of 28GHz (27.68GHz - 28.55GHz, 3.10%). When a Defected Ground Structure in the form of a ring is properly inserted in the ground plane, a new frequency band at 38GHz (2.81%) is created. The antenna's gain is 6.87dBi at 28GHz and 4.17dBi at 38GHz. The proposed antenna measures 7.23mm x 7.23mm in size. The performance of the antenna was also enhanced by the addition of Defected Ground

Structure. Additionally, various proposed antenna parameters are varied, researched, and thoroughly discussed to see how they affect the antenna performance [21].

3. Antenna Array on a Wearable Finger Ring for 5G/mmWave Applications

The communication systems of fifth-generation now includes a massive amount of body-centric (Wearable) wireless communication. Its popularity is growing as a result of numerous contemporary applications, including health monitoring, telemedicine, and personal entertainment. For the 5G/mmWave, a finger ring, wearable antenna array radiating at 28GHz has been proposed in this work. In order to make the antenna wearable, a microstrip patch array is attached to a Teflon ring base. The antenna has been simulated, modeled, and optimized using CST Studio. The results of the simulation show that the suggested design offers a good return loss at the single desired frequency with a peak gain of 5.14dB. It is a suitable candidate due to its good bandwidth and radiation characteristics performance as well as its small size [22].

4. Novel Multiband Microstrip Patch Antenna for 5G Communication in the mmWave Range

An innovative mmWave multiband patch antenna is only designed for 5G communication is presented in this paper. The maximum bandwidth of the 5G mmWave antenna is 5.5 GHz for the 37 GHz band and 8.67 GHz for the 54 GHz band. The microstrip technology-based 5G mmWave multiband antenna is less expensive, low profile, high gain, and efficiency features. CST MWS, a simulation program, is used to design the 5G antenna. Its tiny form factor measures 7.2×5.0×0.787 mm^3. The realized gain of the 5G antenna is sufficient at 5 dBi and 6 dBi. It is simple to use and can support 5G communication in smart devices [23].

5. Dual band antenna printed in 3D at a minimal cost for mm-wave 5G applications

This study presents a streamlined, inexpensive, and highly effective microstrip patch antenna with a feeding, suitable method and dielectric substrate for use in the 28 GHz frequency range. A rectangular microstrip patch antenna, dual band for 28GHz and 38GHz communications was created and examined using 3D printing. The idea behind the design is to etch slots into the microstrip patch antenna's copper patch as intended for operation at 28GHz in order to enable operation at 38GHz. The suggested antenna offers a 6% (28.35 to 29.9) and 5.3% impedance bandwidth (36.89 to 39). The gain in the E-plane at 28GHz and 38GHz, respectively, are 5.126dBi and 5.011dBi [24].

6. A packaged antenna for a 5G mmWave implementation

The interconnection loss between the silicon chip and the antenna in the millimeter-wave band presents a challenge for system simulation, integration, fabrication, and implementation, necessitating a trade-off in material, circuit, packaging, and radiation quality. In this paper, loss and impedance matching for antenna in package, antenna on chip, and hybrid solutions will be compared from an electromagnetic point of view. Then, we demonstrate a cheap antenna that operates in the mm-wave band. Lead connection is chosen over electromagnetic coupling to lower interconnection loss. The suggested antenna can achieve a peak realized gain of 6.14 dBi and an impedance bandwidth of 29.1% between 25.5 and 34.2 GHz, making it suitable for 5G communication [25].

7. An Antenna with a Rectangular Microstrip Patch for 5G Applications at 28 GHz

Due to the demands of small, fast, and wide bandwidth systems worldwide, communication systems have been pushed toward the fifth generation (5G). A microstrip patch antenna, which is rectangular in shape operating at 28 GHz is created and simulated in this study. The patch measures 6.285 mm by 7.235 mm by 0.5 mm in its compact form. The suggested antenna has an efficiency of 70.18%, a reflection Coefficient of 13.48 dB, a bandwidth of 847 MHz, a gain of 6.63 dB, and a resonance frequency of 27.954 GHz. The 50 microstrip feedline and radiating patch are matched using an inset feed transmission line technique. A substrate, Roger RT Duroid 5880 having a height of 0.5 mm and a dielectric constant of 2.2 was used in the design. It also has a loss tangent of 0.0009. Using Computer Simulation Technology Microwave Studio, the antenna's geometry was calculated, and the results of simulations were presented and examined [26].

8. A Microstrip Patch Antenna for 5G Devices at 28 GHz

This paper presents the design and simulation of a unique microstrip patch antenna for 5G communication operating at 28 GHz. The antenna's center frequency is 27.91 GHz, its maximum reflection coefficient is -12.59 dB, its bandwidth is extremely wide at 582 MHz, and its gain is high at 6.69 dB. It operates in the Local Multipoint Distribution Service band. An inset feed serves as the antenna's transmission line. The substrate name is Rogers RT Duroid 5880, which has a height of 0.254 mm and a low dielectric constant of 2.2. The antenna parameters were calculated, and HFSS was used to display and analyze the results of simulations [27].

9. **Flexible PET-Based Millimeter-Wave Antenna Printed with Inkjet for 5G Wireless Applications**

In this paper, a flexible millimeter-wave (mm-wave) antenna for wireless applications such as fifth-generation (5G) is presented. It was developed on a PET substrate. An integrated T-shaped patch and symmetrical slot arrangements make up the antenna geometry. To increase bandwidth, using the defected ground structure (DGS) concept, a slotted monopole antenna fed by a coplanar waveguide (CPW) is embedded inside a ground plane aperture. The inkjet-printed antenna prototype's measurements show that its impedance bandwidth ranges from 26 to 40 GHz, it radiates omnidirectionally consistently, and its peak gain at 39 GHz is 7.44 dBi. The proposed antenna may find use in future 5G applications, particularly in wearables like uniform or casual clothing, according to the conformity and flexibility [28].

10. **A small, triple-slot rectangular microstrip patch antenna for 5G connectivity using Metamaterial**

In this paper, various RMPA architectures are proposed to examine a 5G sub-6 GHz operating antenna for wireless communications. To create an antenna that is both small and highly effective, the antenna design is gradually optimized. In the beginning, a 3.13 GHz Rectangular Patch Antenna (RPA) (novel) structure is presented. A Metamaterial (MTM) ground is added after the primary structure has been examined and optimized. Resonance is present in the designed RPA with MTM ground at frequencies of 3.27 GHz, 3.78 GHz, and 3.92 GHz. A Rectangular Microstrip Patch Antenna, Triple Slotted (TSRMPA) with MTM ground is finally realized by retuning the RPA structure by adding three slots at the top right edge of the antenna patch. By modifying the structure without changing the dimensions, the designed antenna is tuned to operate at sub-6 GHz. With a good reflection coefficient performance of -30.77 dB and a gain of 5 dB, the compact antenna with MTM ground resonates at 3.5 GHz. Compact antenna with MTM ground measures 30.2 x 36.4 mm^2. Software called High Frequency Structural Simulator (HFSS) is used to research these antennas. In order to demonstrate the effectiveness of the suggested antenna design, good agreement between the results of simulation and testing is presented [29].

11. A 5G ultra-low-profile MIMO antenna for smartphone

The MIMO application of mobile devices is presented with a low-profile wideband antenna. Inverted-F antennas (IFAs) are used to create the antenna by mounting them to a synthetic magnetic conductor (AMC). A wave mode (surface) on the AMC is excited in addition to the local resonant at the frequency of in-phase reflection to increase the bandwidth. In the presence of surface wave, an efficiency radiation is formed by the design of the IFAs and their positioning on the AMC. An 8-element MIMO antenna is designed and constructed as an example. The antenna's overall dimensions are 140 mm by 70 mm by 0.97 mm. The measured efficiency is greater than 50% and the bandwidth ranges from 3.3GHz to 3.8GHz. The working platform has little impact on the antenna efficiency, and the antenna can be integrated into the back cover of smartphones [30].

12. A 28 GHz Microstrip Patch Antenna for 5G Communication Systems: Design and Analyzation

This paper represents the design and performance evaluation of a 28GHz microstrip patch antenna (MSPA) for fifth-generation (5G) wireless communication systems. In order to operate at 28 GHz, the antenna is modelled with a substrate called FR-4 material with a thickness of 0.244 mm and a dielectric constant (r) of 4.4. It is then simulated in CST (Computer Simulation Technology) and analyzed. According to the results of the simulation, the beam has a gain of almost 7.587 dBi, a directivity of nearly 7.509 dBi, an efficiency of 98.214%, and a bandwidth of 1.046 GHz. The proposed antenna significantly outperforms other comparable designs in terms of beam-gain, return loss, bandwidth and radiation efficiency. So, the proposed antenna performs very well in comparison to other works and may be a candidate antenna type for mmwave 5G communication systems [31].

13. The MTM-inspired resonators were used to design a wideband sub-6 GHz 5G MIMO antenna with isolated enhancement.

In this paper, a low-profile wideband multiple-input, multiple-output (MIMO) antenna for 5G new radio applications is proposed. It operates at a frequency of sub-6 GHz. In isolation enhancement, the metamaterial (MTM) structures of the ENG were applied. The proposed flag-shaped (Unique) MIMO antenna with MTM which has achieved high isolation at frequency ranges of 3-6 GHz. The lowest transmission coefficient measured at 3.7 GHz was 40.58 dB. The transmission coefficient looked into the diversity performances (isolation). The diversity gain exceeded 9.95 dB, and the envelope correlation coefficient that was less than 0.025 dB. Additionally, at 3.1 GHz, the maximum gain was 3.28 dBi. The radiation was almost omnidirectional in nature. The proposed MIMO antenna which is flag-shaped is appropriate for new 5G radio applications operating below 6GHz [32].

14. A high-isolation wideband MIMO antenna for 5G applications

This letter presents a design for a wideband, four-element MIMO antenna that covers the 1.9–5.2 GHz frequency range and has improved isolation. The basic design of the proposed MIMO antenna is a meandering single monopole; a dual-band is produced by coupling an inverted-F and meandering L-shape strip, and wideband is produced by coupling a parasitic strip. Etching two slots H-shape and two split-ring resonator slots respectively at the ground can improve the isolation between two adjacent input ports. The dielectric plate is surrounded by symmetrically rotating antenna elements that are distributed vertically. The MIMO array's overall dimensions are 54 mm by 120 mm by 13 mm. An effective layout can minimize the user's impact on antenna performance, allowing each antenna element to function normally. The prototype is manufactured, measured, and simulated. The antenna's gain is 6.1 dB at 3.6 GHz, and Its return loss is 10 dB for good impedance matching, and its isolation is high (16 dB), total efficiency is high (>65%), and its envelope correlation coefficient is low (ECC 0.05). It is discovered through measurement that the outcomes are essentially in line with the outcomes of the simulation, proving that wide bandwidth and high isolation can both be attained and used successfully in 5G communication [33].

15. An extremely effective 2x2 antenna array operating at 28 and 38 GHz for 5G applications

One of the most difficult problems at the moment is the design of microstrip patch antennas (MPAs) in terms of 5G requirements. The purpose of this work is to create an effective 2x2 antenna array at 28 GHz and 38 GHz in accordance with 5G specifications. Due to its low cost, low profile, and ease of production, MPA is widely used in wireless technology; however, an analysis of earlier work shows that those antennae did not adequately address 5G requirements. The 2x2 antenna array in this work is designed for both 28GHz and 38GHz. Foam was used as the substrate element for both antenna designs, with a substrate height of 0.5 mm. The feeding method used was a quarter-wave feeding. With bandwidth, return loss, gain, VSWR, and antenna efficiency of 1.3GHz, 61.19 dB, 15.4 dB, 1.001, and 97.97% at 28 GHz, and 2.49GHz, 52.28 dB, 13.8 dB, 1.005, and 97.97% at 38 GHz, respectively, the recommended 2x2 antenna array demonstrated excellent performance. The recommended antenna covered all useable basic requirements better than the previous works, according to a comparison between the recommended antenna array and earlier work [34].

16. Optimization of Microstrip Patch Antenna Design Specifications at 28 GHz and 38 GHz for 5G Application

This effort was motivated by the fact that 5G antenna design is currently a significant and challenging issue. Designers of 5G antennas at 28 GHz and 38 GHz are having difficulty meeting 5G requirements. This issue is adequately covered in the literature review that follows. At 38 GHz, a single element MPA's return loss and gain are 15.5 dB and 6.9 dB, respectively, and at 54 GHz, they are -12 dB and 7.4 dB, respectively. The return loss was close to -10dB, proving the effectiveness of this antenna. In order to support 5G, the tri-band MPA was designed. This antenna's bandwidth measured 900 MHz at 28 GHz and 480 MHz at 38 GHz. In addition, a gain of 7.02dB at 28 GHz and a gain of 5.05dB at 38 GHz were achieved. It is difficult to fill the channel bandwidth with such capacity given that the standard for 5G channel bandwidth is 1 GHz. Additionally, the increase is lower than what is needed for standard 5G. A unique multiband MPA with bandwidths of 5.5 GHz at 37 GHz and 8.67 GHz at 54 GHz has been built. This antenna receives more bandwidth because the expanded bandwidth uses more battery power than the actual 5G antenna, wasting the entire working frequency. Additionally, the gain at 54 GHz is 6 dB and at 37 GHz is 5.5 dB, which does not meet 5G requirements. Air has been used to construct the substrate for a single-element high-gain antenna. Although the final parameters met the 5G standard, this antenna is constructed on an air substrate, which is challenging to use in actual applications. The substrate component, height, and feeding strategy all affect an antenna's effectiveness. If these are not properly chosen, the 5G requirements won't be met. In order to manufacture MPA at 28 and 38 GHz that meets 5G specifications, this research identified the ideal value of the substrate element, substrate height, and feeding mechanism. Additionally, the effectiveness of antennas made using these three design parameter values is contrasted [35].

17. 5G communication utilizing a 28 GHz printed antenna with enhanced gain

In this work, a straightforward rectangular microstrip feed antenna for 5G communication is developed. The suggested structure has the following measurements: 7.9 x 14.71 x 1.6 mm, with FR-4 as the used substrate. The antenna can operate between 27.67 GHz and 28.31 GHz. -14 decibels or more is the reflection coefficient. Using simulated s11, VSWR and surface current and radiation pattern data, it is demonstrated that the designed structure is the best option for 5G communication system. In the operational band, the radiation pattern is also dependable. The suggested framework includes three evolutionary stages. On a FR4 substrate, all structures for the 28 GHz 5G communication frequency are constructed. It operates between 27.58 GHz and 28.53 GHz and has a working spectrum maximum gain of 7.2 dBi. The suggested structure is better suited for 5G communication because it is low profile and simple to install on MMIC devices [36].

18. Microstrip Antennas for Increasing Bandwidth with Various Parasitic Patches and Shorting Vias

Two new microstrip patch antennas with numerous parasitic patches and shorting vias have been proposed to increase bandwidth. The typical triangle patch antenna can be extended to form two additional resonances, resulting in a wider antenna bandwidth. The measured 10-dB impedance bandwidth of this antenna between 5.5 and 6.55 GHz is 17.4 percent. This antenna was also constructed and tested. To construct three resonances, this article first develops a one-of-a-kind microstrip patch antenna with many parasitic patches. When parasitic patches are incorporated into the design of the suggested antenna, two additional resonances may be attained, greatly increasing the bandwidth. Using a parametric approach, the impact of dimension factors on antenna performance was assessed. The previously mentioned antenna is then given two shorting vias, which enables the input impedance to be reduced at specific frequency ranges and, as a result, further expands the bandwidth. To verify the design principles, two examples of the suggested antennas were built and tested. According to the data, the impedance bandwidths of these two S11 0 dB antennas cover 5.46 to 6.27 GHz (13.8%) and 5.5 to 6.55 GHz (17.4%), respectively [37].

19. Grid Pattern and Frequency Reconfigurable Array Antennas at 28 GHz Comparison

For fifth generation (5G) communications, A square array antenna for millimeter waves is shown. The 20 cell which are nearly-rhombic, 40×40 mm^2 Square Array Antenna construction is simulated and constructed using the Rogers RT/Duroid 5880 substrate with a thickness of 0.25 mm. The simulated grid array has |S11|; -10dB for two frequency ranges neighboring in the upper 26 GHz millimeter wave spectrum and has a percentage bandwidth and gain of 5.41% and 16.5 dBi, respectively. Using the same substrate and dimensions, the antenna is differentiated to a Microstrip Patch Array [38]

20. Novel Microstrip Antenna Design with Enhanced Bandwidth

This study suggests a novel broadband patch antenna architecture. The size and locations of the slots and notches on the radiating patch are precisely calculated to produce the broadband functionality of the suggested antenna. The bandwidth of the proposed antenna, with an operational frequency range of 1.56 GHz to 2.12 GHz, is found to be 30.5 percent, or roughly 430 MHz. Antenna characteristics and their effects on bandwidths are examined for different inclination angles. With a maximum gain of 9.86 dBi and a broadside radiation pattern that maximizes radiation in all operating bands, the antenna has a maximum gain. The recommended antenna construction is created, made, and tested to achieve the desired performance. Comparing the results from the simulation and the experiment, it can be seen that they are fairly similar. Traditional microstrip patch antennas' primary flaw is their small bandwidth, which severely limits usage. As a result, engineers, scientists, and researchers started working very hard to increase patch antenna bandwidth. To increase bandwidth, slots and notches of various sizes and shapes can be loaded onto the patch or the ground plane. Although there are other ways to increase bandwidth, this technology makes it simple to manufacture, load, and increase bandwidth without adding to the bulk of the structure [39].

21. A quarter-array and millimeter-wave 1×4 microstrip array antenna for 5G communication

To be utilized for 5G communication, A millimeter-wave microstrip patch antenna and its 1×4 array were suggested in this research.The millimeter-wave microstrip patch antenna was made using the RT/duroid 5880 substrate material with a relative permittivity of 2.2, and its substrate cut slots were filled with air. This antenna is fed via the microstrip line feeding technique and has a relative permittivity of 1. The proposed antenna would have a return loss of 15.38dB and a gain of 9.6dB at a frequency of 31.76GHz. The 14-element antenna array is designed with dimensions of 3512 mm 2 and uses air as the heterogeneous substrate in addition to low-cost substrate RT/duroid 5880 materials. At resonant frequency 28.78GHz, the 1/4 array's return loss is 51.63 dB, while its gain is 10.83 dB [40].

22. Microstrip Patch Antennas for Increasing Bandwidth with Multiple Parasitic Patches and Shorting Vias

Two new microstrip patch antennas with numerous techniques have been proposed to increase bandwidth. The typical triangle patch antenna can be extended to form two additional resonances, resulting in a wider antenna bandwidth. The measured 10-dB impedance bandwidth of this antenna between 5.5 and 6.55 GHz is 17.4 percent. This antenna was also constructed and tested. This article first develops a unique microstrip patch antenna with numerous parasitic patches in order to build three resonances. When parasitic patches are incorporated into the design of the suggested antenna, two additional resonances may be attained, greatly increasing the bandwidth. Using a parametric approach, the impact of dimension factors on antenna performance was assessed. The previously mentioned antenna is then given two shorting vias, which enables the input impedance to be reduced at specific frequency ranges and, as a result, further expands the bandwidth. To verify the design principles, two examples of the suggested antennas were built and tested. According to the data, the impedance bandwidths of these two S11 0 dB antennas cover 5.46 to 6.27 GHz (13.8%) and 5.5 to 6.55 GHz (17.4%), respectively. Both of them have the ability to set up a fantastic long field [41].

23. For C-band applications, a High Gain 4×4 Microstrip Square Patch Array Antenna

A C-band satellite reception antenna needs a high gain to connect to the long-distance wireless communication between the ground station and satellite. Microstrip antennas have the following advantages over other types of antennas: low profile, ease of fabrication, ease of feeding, ease of integration with other microstrip circuit elements and systems, and simplicity of use when used in an array to boost directivity. This study proposes a quarter-wavelength transformer impedance matching scheme, a microstrip array antenna, and a patch radiating element with a 4×4 rectangular shape. With the array antenna technique, higher directivities and high gains are the goals. This research has considered a FR-4 Epoxy substrate to install the antenna construction, choose a material whose thickness and dielectric constant are, respectively, 1.6 mm and 4.3. For the best performance, the antenna design is parameterized and designed to simulate using CST Microwave Studio. The 4*4 microstrip rectangular patch array antenna has a gain of 13.7 dB overall, and the return-loss graph indicates that its working bandwidth is 734 MHz, which spans the frequencies of 3.794 and 4.528 GHz. These results show that the suggested antenna design is appropriate and promising for C-band satellite applications [42].

24. Novel Multiband Microstrip Patch Antenna for 5G Communication in the mmWave Range

An innovative mmWave multiband patch antenna design for 5G communication is presented in this paper. The maximum bandwidth of the 5G mmWave antenna is 5.5 GHz for the 37 GHz band and 8.67 GHz for the 54 GHz band. The microstrip technology-based 5G mmWave multiband antenna has low cost, low profile, high gain, and efficiency attributes. CST MWS, a simulation program, is used to design the 5G antenna. Its tiny form factor measures 7.2×5.00×**0.**787 mm^3. The realized gain of the 5G multiband antenna is sufficient at 5 dBi and 6 dBi, respectively. It is simple to use and can support 5G communication in smart devices [43].

25. Rectangular Patch Array 1 x 2 MIMO Microstrip Antenna with Tapered Peripheral Slits Design for 28 GHz Band 5G mmwave Frequency

The 5G network was designed for high-speed wireless data transmission. An antenna with a MIMO system is one of the features that needs to be developed well to support the massive data transmission via wireless communication. In this paper, we suggest a microstrip antenna with a tapered peripheral slits method and a rectangular MIMO array 1×2. It was suggested that this antenna operate at 28 GHz for 5G wireless communication. It will also use a tapered periperal slit approach to lower the size of the microstrip antenna in addition to other downsizing techniques to obtain a smaller microstrip antenna size. Our antenna's dimensions were only 16 mm by 14 mm when using this design. Additionally, the frequency band we used was 28 GHz, with the frequency center being 27.8 GHz (in simulation) and 27.44 GHz (in measurement), the bandwidth being 5.68 GHz (in simulation) and 1.57 GHz (in measurement), and the S11 parameter being -32.89 dB (in simulation) and -21.14 dB (in measurement) [44].

26. Triple Band Antenna for 5G Applications

This work presents a multiband compact patch antenna using a single substrate of microstrip. Future 5G applications can use the antenna since it works in the 30GHz–300GHz millimeter wave frequency band. The resonance frequency of the triple band microstrip patch antenna is 26.92GHz, 35.08GHz, and 54.74GHz. The antenna has a -52.87dB return loss, a 13.92% bandwidth, and gains of 6.36dB and 6.36dB, respectively, at 54.74GHz. These results demonstrate the antenna's suitability for potential 5G applications. [45].

27. Design of a Linear 2 x 2 Array Using a Patch Antenna with Substrate-Integrated Waveguide for 28GHz mm-Wave Usage

In this study, we propose a redesigned and substrate-integrated wave guide-fed linear array patch antenna for 28GHz millimeter-wave applications. A 2x2 array structure's elements are initially given slots, and the slots are subsequently used to excite patches. Port count was decreased from N2 to N in the subsequent design. For a 2 x 2 array antenna, this arrangement only requires two ports. The cost of fabrication and the complexity of the circuit are decreased using this feeding technique. The substrate integrated wave guide (SIW) is a feeding technology provides a low side-lobe power level and provide side-lobe suppression. Average gain values of 9.2dBi were obtained for the proposed system, which has a reflection co-efficient of approximately 22.5dB across the band. This technique has good VSWR throughout the entire operating band with a center frequency of 28GHz. Additionally, it is simple to integrate with various RF circuits and is used in upcoming 5G mobile communications [46].

28. Antenna for mmWave 5G Mobile with Series Chained Patch Phased Array and Metal Bezel Design

In this study, a series chained patch phased array antenna is suggested for use in metal bezel mobile applications that operate at 28GHz for millimeter-wave (mmWave) 5G communication. The suggested antenna is a two by four series chained patch array mounted on a mobile device's metal bezel corner. It is also intended for beam steering in the xy and yz planes. In order to increase the durability and metal fabrication of the patch element, a metal chain is added and used. The proposed antenna's xy-plane maximum gains are 12.8 dBi, 12.9 dBi, and 13 dBi. At the xy plane, the beam steering angle is 45 degrees, and at the yz plane, it is 30 degrees. In relation to the intended mmWave 5G mobile application, results of measurements, simulations, and particular design techniques are shown and discussed. [47].

29. Compact Wideband Antenna-in-Package Based on PCB Technology for 39 GHz 5G mmWave Applications

This paper introduces a small wideband antenna-in-package (AiP) for 39 GHz frequency band 5G mmWave applications. Two identical patch antenna elements make up the proposed 1x2 antenna array, which was simulated, designed, and manufactured using a multilayer of PCB substrate technology appropriate for chip embedding. Each patch element has two U-shaped slots etched into it to increase the antenna bandwidth. The fabricated 1x2 U-slot patch, antenna array has a measured peak gain of 8.8 dBi and a measured impedance bandwidth providing 3 GHz at the 39 GHz frequency band [48].

30. Analyzing 5G mmWave antenna arrays on various substrate technologies in comparison

Researchers identify the effects of various substrate technologies differentiate the core performance of mmwave 28 GHz antennas for the 5G applications in this work. After modeling, simulating, analyzing, and comparing 2×2 patch antenna arrays of five substrate techniques typically used for producing integrated antennas in order to achieve this. These substrates have a quantifiable effect on the antennas' gain, efficiency, and impedance bandwidth. The antennas are created and measured in the end. Measurement and simulation results exhibit excellent correlation [49].

2.2 Summary

According to a study, microstrip patch antennas for 5G communication have been developed in millimeter wave bands like 28 GHz. According to recent research, the millimeter waves band at 28 GHz holds the most promise and significance for 5G wireless communication. Major research has been done in this frequency band. Again, creating an antenna that is efficient, easy to manufacture, small enough, and has a high gain to compensate for significant route loss is the most challenging task in 5G deployment. To maximize the gain and efficiency, moving towards an array antenna is appropriate.

2.3 Objectives

- The gain for 5g applications was increased by designing and simulating a single microstrip patch antenna.
- Creating the best antenna with increased gain for 5G applications by adjusting various antenna design parameters.
- Using different dimensions, such as insertion gap, patch width, and patch length, to design antenna for 5G applications.
- Designing and simulating a microstrip patch antenna with improved antenna properties, especially in terms of gain, reflection coefficient, efficiency for 5G applications.
- Finally, pick the antenna with the best performance in comparison to the current 28 GHz microstrip patch antennas.

Chapter 3
Methodology

3. 1 Methodology

Methodology is the formal, theoretical examination of the techniques used in a field of study. It entails a theoretical evaluation of a selection of approaches and beliefs pertinent to a particular area of study. Common concepts include norms, theoretical frameworks, stages, and quantitative or qualitative research methodologies. A technique is a planned series of steps or methods. This phrase can refer to customs typical to a field or industry, such as the research techniques used in a specific study. On the other hand, a methodology is distinct from a technique in that it does not aim to provide answers. A methodology is concerned with theoretical support to determine whether an approach or set of procedures is workable in a specific circumstance [50].

A research-based strategy gives the study credibility and ensures that all outputs are reliable scientific conclusions. Additionally, it offers a highly thorough scientific framework that facilitates the process and keeps researchers on track while still making it simple, efficient, and manageable. By comprehending the study process, the reader may grasp the plan and steps used to get findings.

3.2 Research Design

The research design is the framework for addressing the problems raised by the study. An experimental design, a research question, dependent and independent variables, methods for data collection, and a plan for statistical analysis are all examples of research tools that are specified in a study project model.

The research design for the study was as follows:

- Analyzing of the development of 5G technology.
- Studying requirements of the antenna for 5G networks.
- Choosing the millimeter wave band for 5G.
- Researching the literature on current 5G antennas and microstrip antennas.
- Studying The process of creating a microstrip antenna needs to be researched.
- Determining the variables required to build an antenna.

- Finding the ideal dimension values for different parameters like the patch length, patch width, substrate thickness etc.
- Determining the ideal design for 5G applications requiring high bandwidth.
- Choosing your feeding strategy.
- Executing the procedure.

3.3 Pilot Study

Before beginning a full-scale research project, to determine the viability, a pilot study, trial project, pilot test, or pilot scientific experiment is conducted on a small scale. time, cost, hostile various occurrences, and develop the nature of the study. Before the research is organized, it is completed. Pilot studies are typically carried out as intended for the research. A pilot study can't completely rule out due to systematic errors or unanticipated issues, but it significantly reduces the number of errors that the initial study won't be time- or effort-wasting.

Importance of Pilot Research:

- To put the protocol and/or study procedure to the test.
- To categorize critical variables and decide how each should be functionalized.
- To develop or evaluate This project's goal is the efficacy of research tools and procedures.
- To evaluate statistical elements in order to set up future research.

3.4 Software

A sophisticated tool for modeling high-frequency components in three dimensions is the Technology for Computer Simulation Microwave Studio (CST), as depicted in figure 3.1. High-frequency (HF) devices like filters, couplers, antennas, single- and multi-layer structures, as well as calculated SI and EMC effects, can all be accurately and quickly analyzed by CST MWS. The Computer Simulation Technology manual states that the discretization of Maxwell's integral equation is how CST functions. It is further stated that in order to compute time derivatives, CST Microwave Studio uses central finite difference methods. Numerous guides claim that CST is effective when applied using the FDTD method. For R&D departments that are heavily focused on technology, CST MWS is the clear choice due to its unmatched performance. CST MWS is an easy-to-use tool that provides quick insight into the Electromagnetic behavior of high-frequency designs behavior [51].

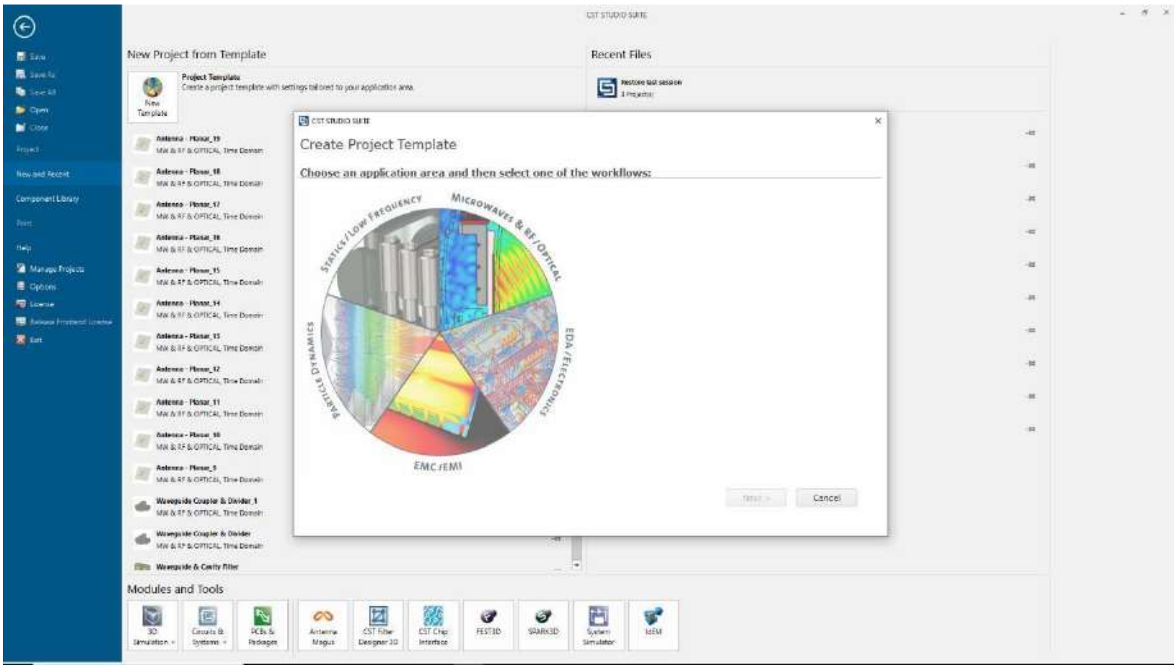

Figure: 3.1 Starting window of CST studio suite application

3.5 Design procedure

Step 1: The first step is to design an microstrip patch antenna, or single rectangular microstrip patch antenna (MPA), which is intended to operate in the 28 GHz band.

Step 2: Save the designed antenna and simulate the antenna built.

Step 3: Save the outcome if the antenna satisfies the criteria

Step 4: To enhance the performance of the antenna, optimize its settings.

Step 5: This step involves designing a 2x2 array of planar antennas that is intended to improve gain, efficiency, reflection Coefficient and directivity.

Step 6: Save the design and test the built-in antenna array.

Step 7: Save the outcome if the antenna satisfies the criteria.

Step 8: Optimize the parameter of antenna array that is designed to improve performance.

Step 9: To Improve the overall performance of the designed Microstrip patch array antenna further design a 4x4 array of planar antennas that is intended to improve gain, efficiency, reflection Coefficient and directivity.

Step 10: Save the designed antenna and simulate whole the antenna that was built. If the outcome isn't satisfactory, optimize the design.

Step 11: Save the outcome if the antenna satisfies the criteria having to improve gain, efficiency, reflection Coefficient, bandwidth and directivity.

Step 12: Compare the results to those 2x2 array, 4x4 array antennas with single rectangular microstrip patch antenna (MPA).

3.6 Antenna Design by Equation

The initial stage in antenna design is to select a suitable dielectric substrate with the requisite thickness. Dielectrics preserve the stability of the mechanical and electrical systems. Additionally, they are employed to lower the antenna's size and facilitate the production of displacement current. which, in accordance with Ampere's Law, produces a magnetic field that varies in strength over time. A time-varying electric field can be formed by this time-varying magnetic field., which, in turn, can result in a propagating electromagnetic field, as per Faraday's rule. In this method, a substrate can enhance the antenna's overall radiating capabilities. Some typical dielectric substrates are listed along with their properties in Table 3.1.

Table 3.1: Substrates List

Name of the Dielectric Material	**Dielectric constant**
FR-4	4.4
RT Duroid-6002	2.94
Rogers RO 3200	3.02
Rogers RT Duroid-5880	2.2
Rogers RT Duroid-5870	2.33
Nylon	3.4
Teflon	2.1

The substrates with relatively high dielectric constants, suggests significant loss when making high-gain antennas. Since MPA designs frequently use Rogers RT-5880, a substrate material with a dielectric constant of about 2.2, as a starting point, we chose it at random. Following that, the microstrip line and the ground material should be selected. In those case, copper, silver, or gold are our three options. Silver has a higher conductivity than other metals do. Contrarily, copper is both much more affordable and robust than the other two metals. Copper is therefore widely used.

Equations (1) -(5) were used to measure the length and width of the antenna [3].

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

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

Effective dielectric constant is given by,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where,

εeff= Effective dielectric constant,
Dielectric constant of substrate, εr = 2.2
Height of dielectric substrate, h =0.50 mm
For the given resonance frequency fr, the effective total length which is given by,

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

The actual length of the patch is given by,

$$L = L_{eff} - \nabla L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where,

$$\nabla L = 0.412h\frac{(\varepsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_r - 0.258)\left(\frac{W}{h} + 0.8\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

The basic parameters of the microstrip patch antenna are calculated using the formulas above and are shown in Table 3.2.

Table 3.2 Antenna Dimension

Parameters	**mm**
Substrate Length	6.36
Substrate width	9.43
Substrate Thickness	0.5
Patch Length	3.18
Patch width	4.71
Patch Thickness	0.035
Ground Length	6.36
Ground Width	9.43
Ground Thickness	0.035
Feed line length	4.04
Feed line Width	0.45
Gap Width	0.20
Parasitic Element	0.4(Outer radius) 0.035(Height)
Slot 1 Length(V)	1.80
Slot 1 Width(V)	0.07
Slot 2 Length(H)	0.20
Slot 2 Width(H)	3

This table shows the parameters that were used for the single element antenna radiating at 28 GHz in mm wave 5G.

3.7 Antenna geometry and designed parameters

Selecting the dielectric substance that will act as the antenna's substrate is the first step. Then, compute a number of parameters with excellent dimensions to obtain better results from the proposed antenna. The proposed antenna is constructed by using Rogers RT 5880 as the substrate material and copper conductor material for the patch and ground plane was used, as shown in figures 3.2 and 3.3

3.7. 1 Microstrip patch Antenna

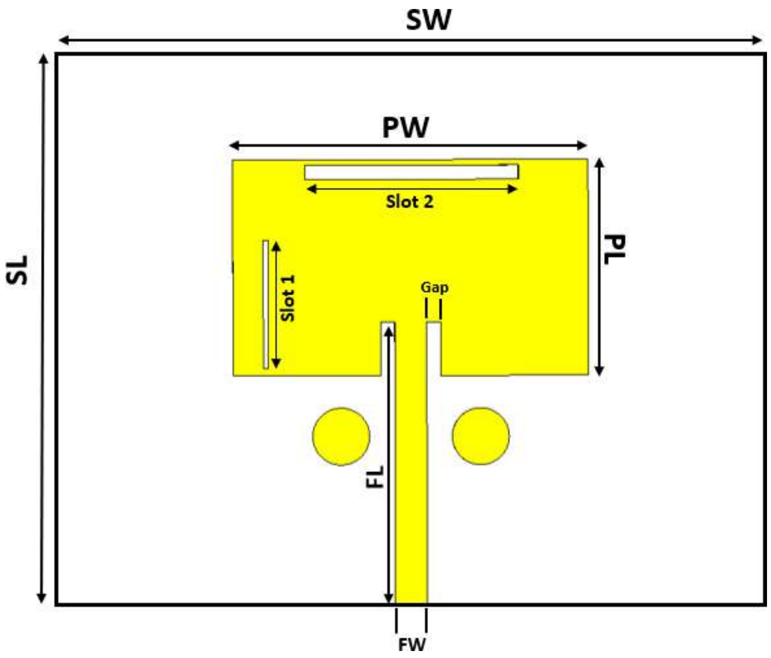

Figure 3.2: Top view of the designed Microstrip patch Antenna

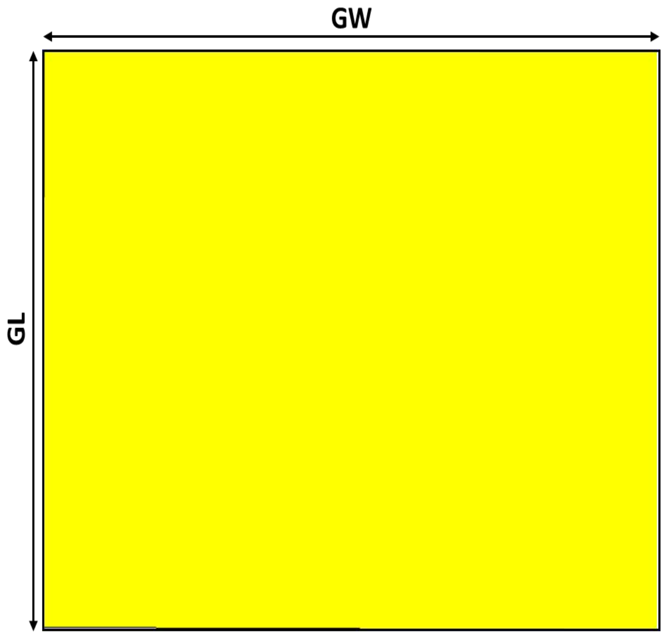

Figure 3.3: Back view of the designed Microstrip patch Antenna

Using the equations from the antenna approach section, Table 3.2 calculates the suggested antenna design parameters for 28 GHz. The height of the substrate was set to Hs=0.5 mm. As a result of the analysis, this parameter might alter in the future.

With the same from factor of the patch and Substrate a 2×2 and a 4 ×4 Microstrip array antenna has been designed. The simulated results of the microstrip patch antenna and array antennas have been discussed in the result analysis segment.

3.7.2. 2×2 Microstrip Array Antenna

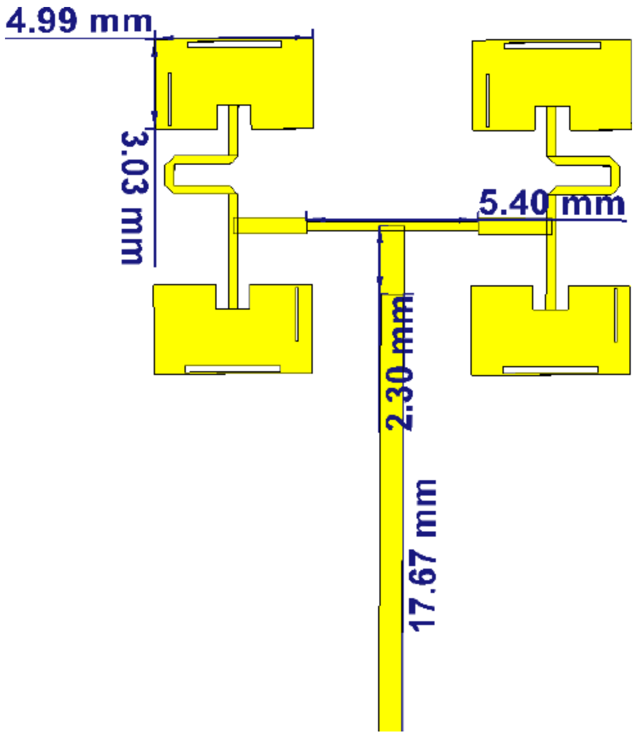

Figure 3.4: Top view of the designed 2×2 Microstrip Array Antenna

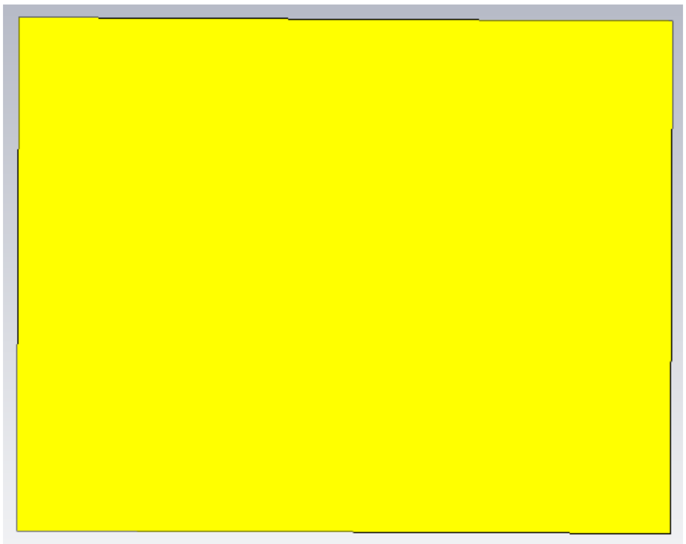

Figure 3.5: Back view of the designed 2×2 Microstrip Array Antenna

3.7.3. 4×4 Microstrip Array Antenna

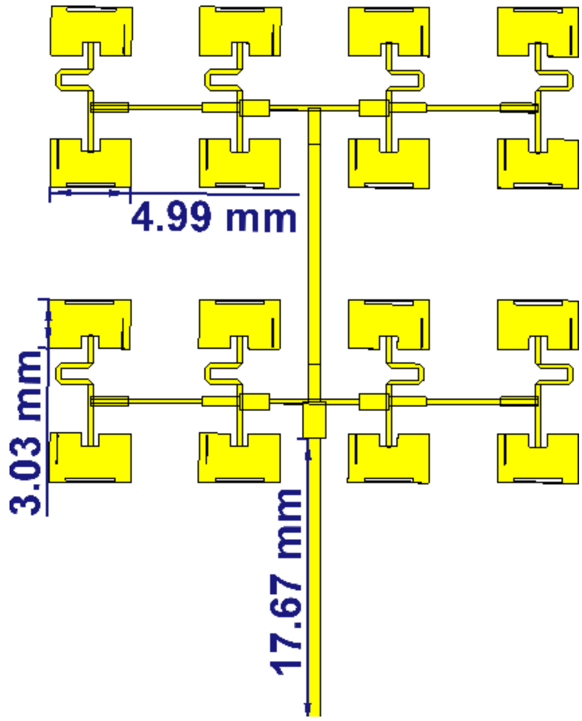

Figure 3.6: Top view of the designed 4×4 Microstrip Array Antenna

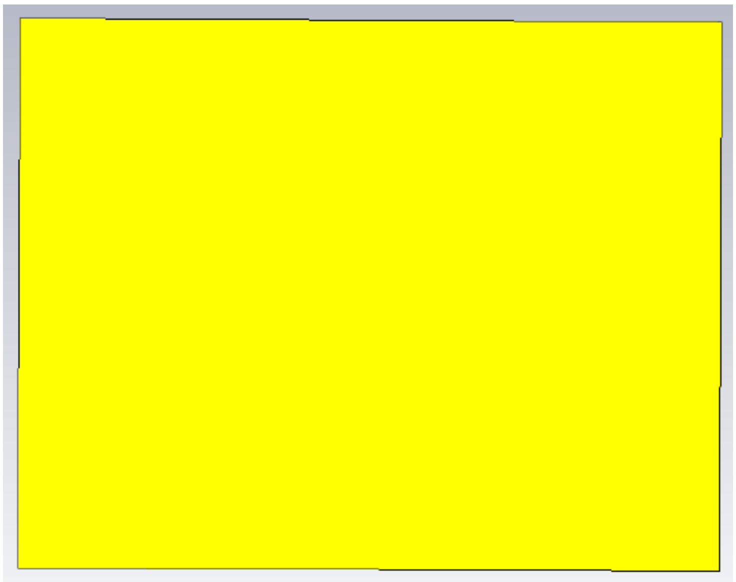

Figure 3.7: Back view of the designed 4×4 Microstrip Array Antenna

Chapter 4
Simulations and Result's Analysis

The results of simulation and analysis are presented and discussed in this chapter.

4. 1 Simulation Results of the Designed Antenna

The investigation and the discussion of the results in this section primarily concentrate on different antenna parameter dimensions. All of the parameters presented in this study were tracked during the analysis. The right antenna is then built using those design parameters, and the final antenna designed parameters are determined by looking at the antenna result parameters.

4. 1. 1 Result analysis of the Designed Antenna

Here, the proposed design process and variables for a mm-wave microstrip patch antenna will be covered. Using an RF calculator, the desired resonant frequency, the dielectric constant, and the substrate thickness are added to calculate the exact patch length, width, and thickness. The calculated values of the patch are 3.18mm in length, 4.71mm in width, and 0.035mm in thickness after inputting the values for E=2.2, thickness 0.5mm, and resonating frequency of 28 GHz.

The first step in designing a compact microstrip patch antenna is to perfectly choose a compatible substrate. Because this antenna radiates in the range of mm wave, the thickness of the substrate should be minimal. The patch's parameter is determined by the substrate's dielectric constant. Since a lower dielectric constant is used at higher frequencies, we used the Rogers RT5880, which has a dielectric constant of 2.2. This will increase efficiency and gain. The calculated patch will then be applied on top of the substrate after that. The simulation has been completed by using the antenna's Table -01 parameter to determine the resonating frequency.

4.2 Optimized Simulation Results

4.2. Reflection Coefficient: The Reflection Coefficient of an antenna is the percentage of radio waves radiating at the antenna given input that are rejected in contrast to those that are accepted [52]. It is measured in decibel (dB). This is also known as s11 parameter. The Lower the value gets the better the antenna will fit in a device or in a Transmission line. The S11 parameter of the proposed antenna is -67 dB and the bandwidth is 1.357GHz that illustrates in Figure 4.1.

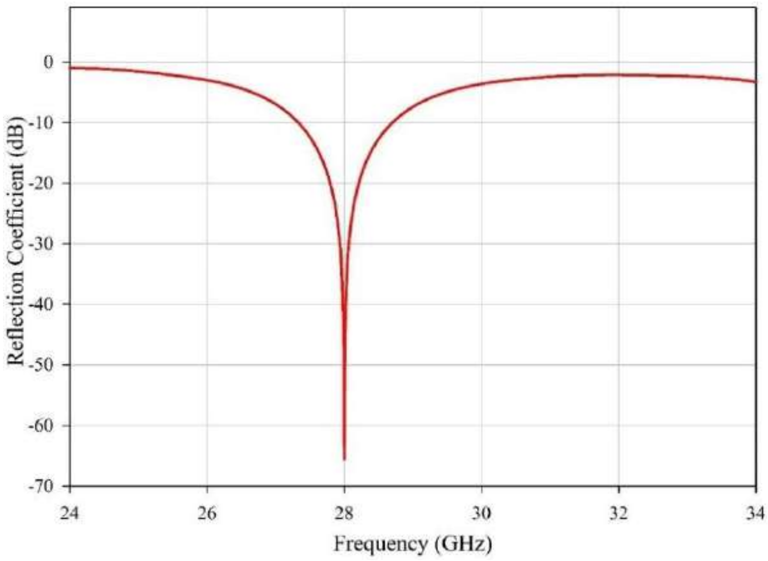

Figure 4.1 Reflection Coefficient of Microstrip Patch Antenna

The Lower the S11 gets the better the antenna will fit in a device or in a Transmission line. The S11 parameter of the proposed designed Microstrip patch antenna is -67 dB and the bandwidth is 1.57GHz alongside it the 1×2 microstrip array has a return loss of -25.75 dB and 2×2 microstrip has -21.66 at 28GHZ, -17.025dB at 31.68GHz that illustrates in Figure 4.2

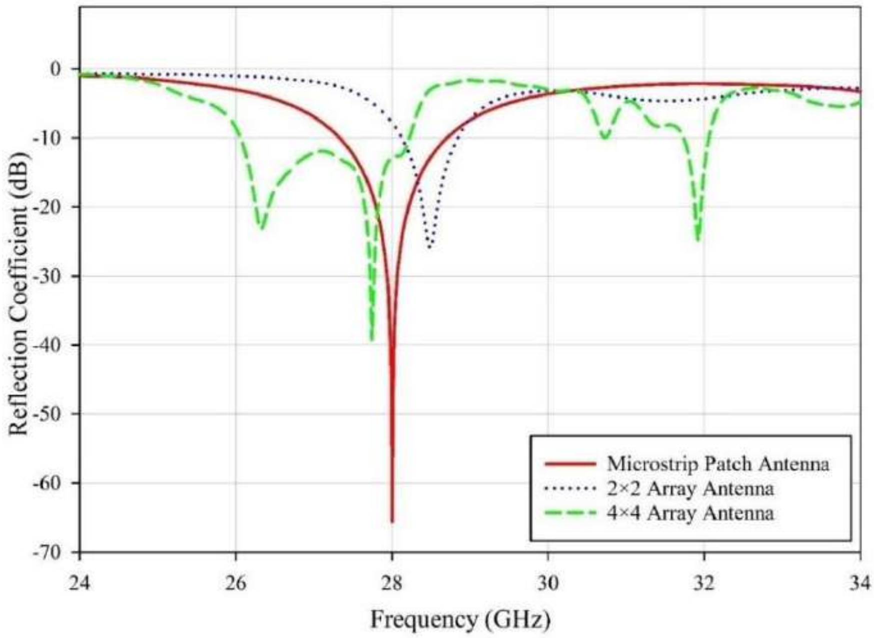

Figure4.2: Comparison of Reflection Coefficient of Microstrip Patch Antenna with array

4.2.2. Voltage Standing Wave Ratio (VSWR)

The VSWR is generally a numerical representation of how well an antenna is impedance matched or transmission line to which it is connected. [52] The better the antenna is matched to the transmission line, the lower the VSWR, and the more power the antenna gets. The VSWR must be at 1.0-2.0. In the proposed antenna at 28 GHz the VSWR is 1.003 as a result almost no power is reflected from the patch antenna in this case, which is very ideal.

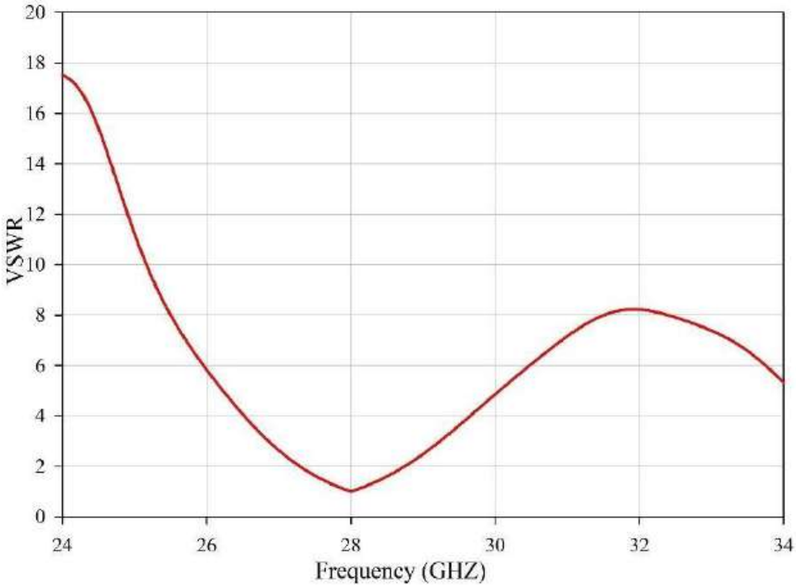

Figure 4.3: VSWR of Microstrip Patch Antenna

Though the VSWR Increases slightly in 2×2 microstrip array VSWR is 1.10 and in 4×4 microstrip array VSWR is 1.19.

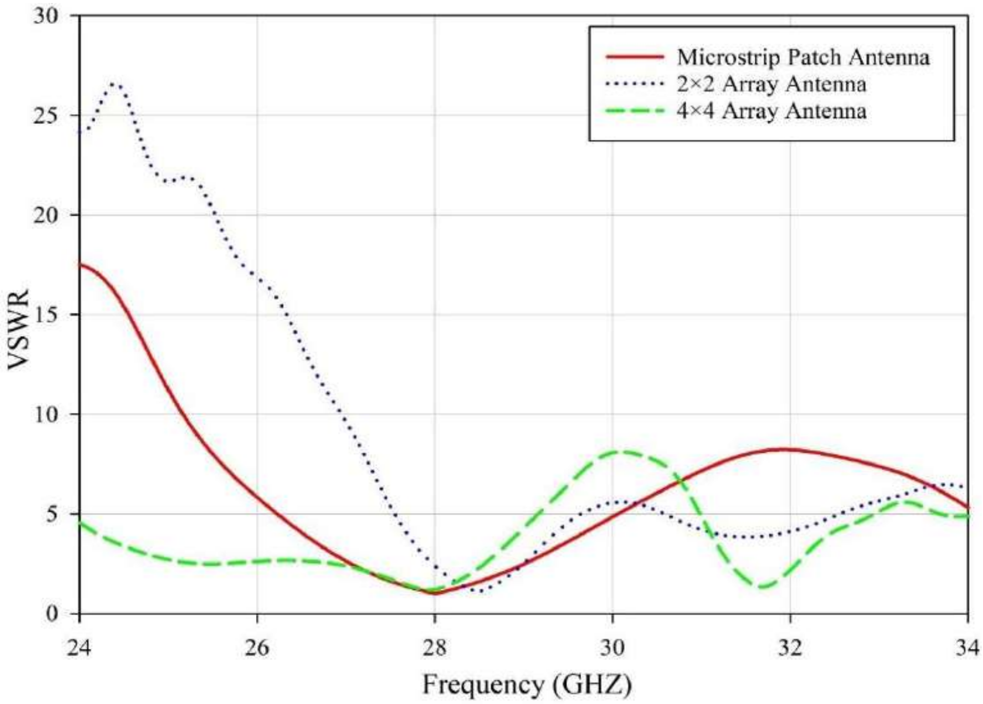

Figure 4.4 Comparison of VSWR of Microstrip Patch Antenna with array

4.2.3 Gain and Directivity

The antenna gain is a direct measurement of how much power the antenna can transmit in the direction of peak radiation. The simulated antenna results a gain of 7.6 dBi, it is regarded as great for a small-from-factor tiny microstrip antenna. Gain is one of the crucial factor to determine the Antenna’s performance. performance in order to increase the gain we have moved towards Microstrip array antenna which helps to achieve a higher gain. In 2×2 microstrip array gain is 13.07 dBi and in 4×4 microstrip array gain is 15.5. In one certain direction the highest gain of the antenna is known as directivity. Directivity follows the same pattern as gain, higher directivity is achievable whining moving towards a higher element array.

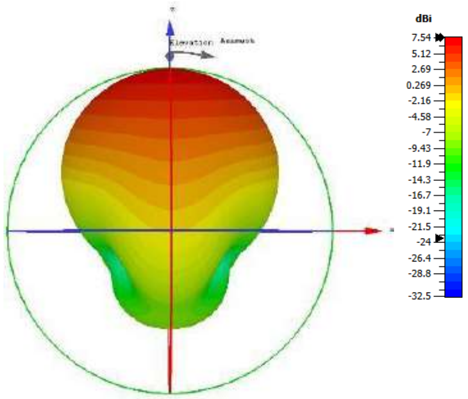

Figure 4.5: Microstrip Patch Antenna Gain

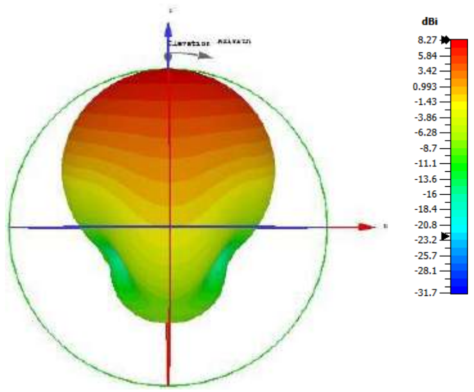

Figure 4.6: Microstrip Patch Antenna Directivity

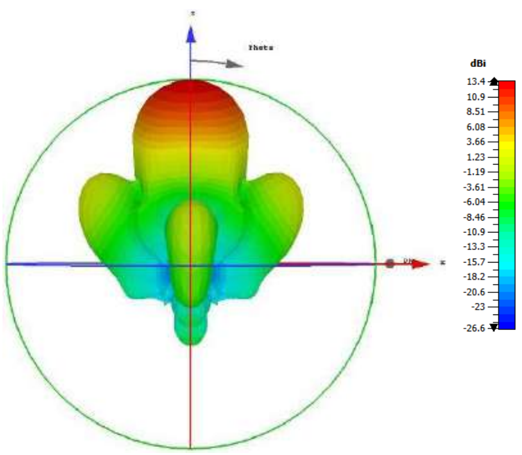

Figure 4.7: 2×2 Array Antenna Gain

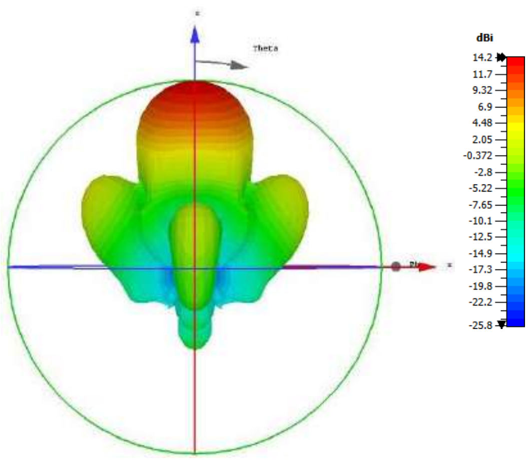

Figure 4.8: 2×2 Array Antenna Directivity

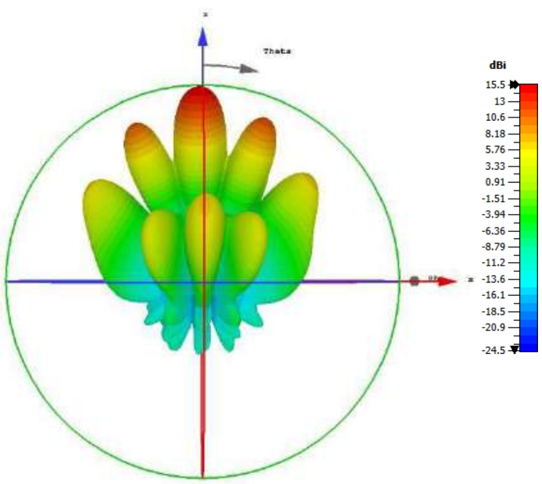

Figure 4.9.: 4×4 Array Antenna Gain

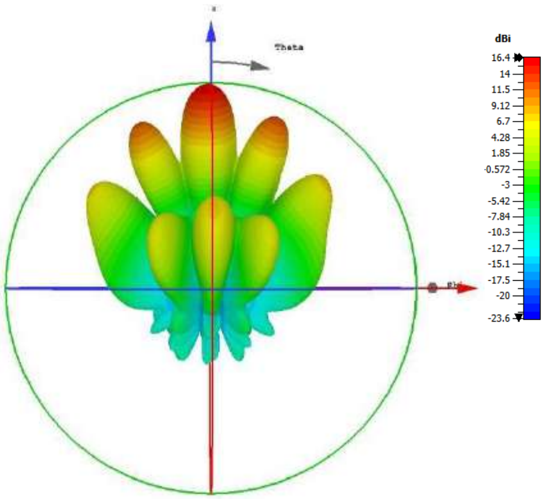

Figure 4. 10: 4×4 Array Antenna Directivity

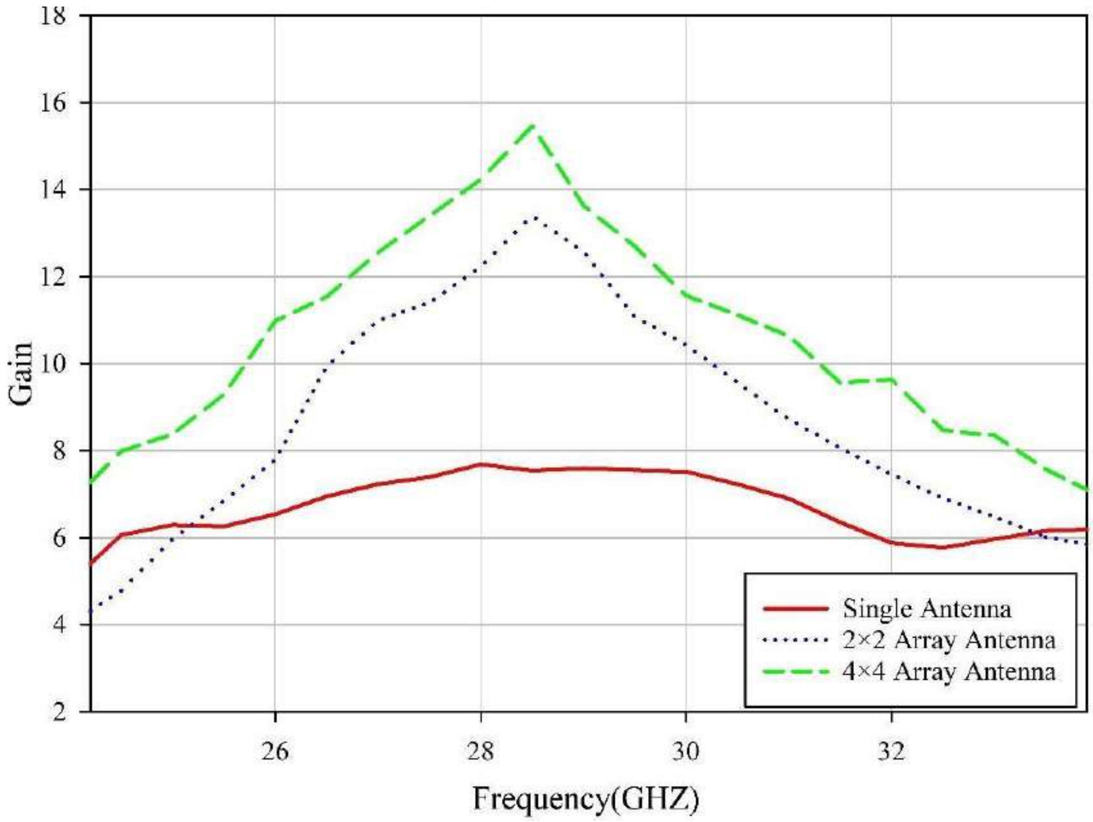

Figure 4.11: 1D gain Comparison of Microstrip Patch Antenna vs Array Antenna

4.2.4 Efficiency

The ratio of the power given to the antenna to the power it radiates is known as the antenna's efficiency. A high efficiency antenna radiates the majority of the power available at the antenna's input power. Due to impedance mismatch in a low efficiency antenna, the majority of the antenna's power is lost as internal losses or reflected away. The proposed antenna has an efficiency of 86%.

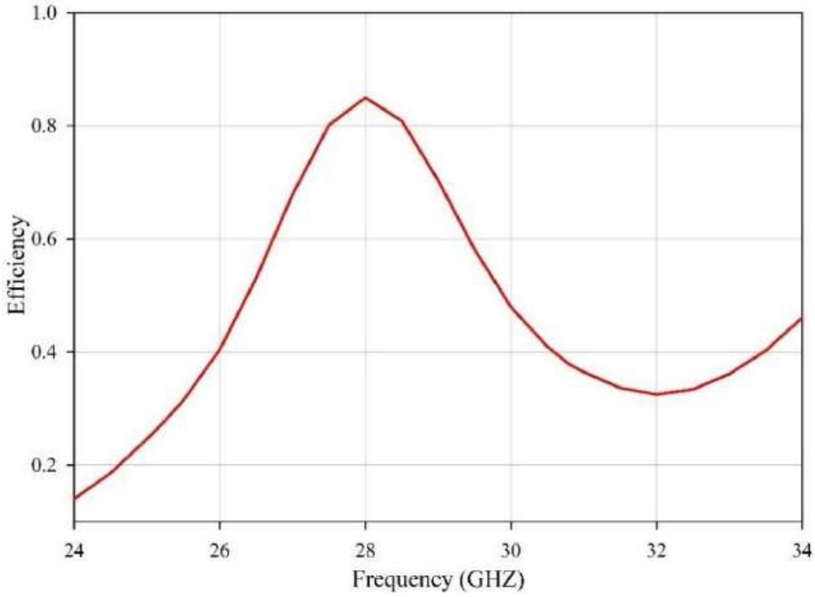

Figure 4.12: Efficiency of Microstrip Patch Antenna

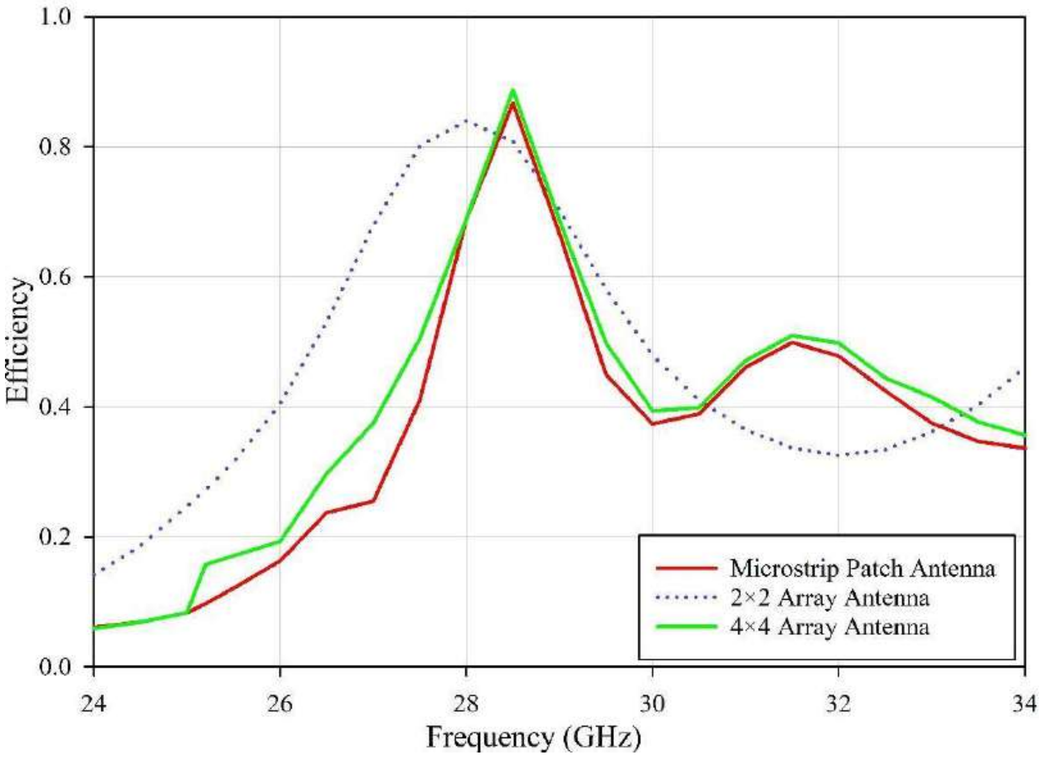

Figure 4.12: Efficiency Comparison of Microstrip antenna Vs Array Antenna

In 2×2 microstrip array antenna's efficiency is 86% and in 4×4 microstrip array efficiency is 88%.

4.3 Comparison

A Comparison table of mm Wave microstrip patch Antenna is manifested in that following table. According to the comparison table reflection coefficient of our proposed is notably better compared to the other antenna, this antenna has a reflection Coefficient of -67dB. Alongside with that our proposed antenna has a much higher gain which is also remarkably higher when compared to the other antenna of that table. Moreover, the total bandwidth of the proposed antenna is also Compare here. The other Parameter such as VSWR and efficiency are also compared on the following table 4. 1.

Table 4. 1 Comparison Table of Proposed Microstrip Patch Antenna and Array with Recent Research Work

Reference	**Gain**	**Bandwidth**	**S11(dB)**	**Efficiency**
[1]	6.72 dB	1.1 GHz	-17.4dB	N/A
[2]	6.87dBi	0.87GHz	-27dB	N/A
[3]	6.14 dBi	N/A	<10dB	N/A
[4]	5.126dBi, 5.011dBi	N/A	-17 dB, -20.45 dB	N/A
[5]	6.63 dB	847 MHz	-13.48 dB	70.18%
[6]	6.69 dB.	582 MHz	–12.59 dB	N/A
[7]	5.14dB			N/A
[8]	5 dBi and 6 dBi	5.5 GHz, 8.67 GHz	-25.8/ -27.8 dB	N/A
[9]	5.32 dBi	4.10 GHz	-39.70 dB,	N/A
[10]	7.44 dBi	N/A	-20, -27, -40 dB	N/A
Proposed Antenna: Slotted microstrip patch antenna	7.6 dBi	1.57GHz	-67dB	86%
2×2 Microstrip Array Antenna	-25.75 dB	13.07 dBi	-28.75 dB	86%
4×4 Microstrip Array Antenna	-21.66 dB	15.5 dBi	-38.86 dB at 27.74 GHZ & -24.47dB at 31.9GHz	88%

Chapter 5
Conclusion

The creation of a 5G compatible microstrip patch antenna was the main goal of this study. We tried to change the parameters' dimensions in an effort to improve the project's results, which will significantly increase the antenna's bandwidth, return loss s11, and VSWR. Then, using those features, a single-element antenna operating at 28GHz was constructed, meeting 5G requirements and outperforming earlier trials. This work was motivated by the fact that current antennas fall short of 5G's exact requirements. Therefore, we changed the parameter dimensions to make this task more efficient, and this change had a special impact on the antenna's bandwidth, return loss, and VSWR.

5. 1 Achievements

A Compact slotted Microstrip Patch Antenna for Mm Wave 5G is designed and simulated in CST Studio 2019 which is highly functional in 5G. The proposed antenna has overall good performance with reflection coefficient of -67dB, gain 7.6dBi, Bandwidth 1.57GHz, Efficiency 86% and its resonates in 28 GHz which frequency is licensed in mm wave in USA, Canada, UK, Germany, Australia, Japan and South Korea. As Substrate Rogers RT 5880 with permittivity of 2.2 has been used and the Patch and ground is constructed of copper aeneled. With same from factor 2×2 microstrip array and 4×4 microstrip array's result is compared in this research, which leads to a overall good performance. The two Slot one vertically and one horizontally cut on the patch plays a significant role to increase the performance of the antenna. The main future work of the antenna is to make it more compact and widen its bandwidth.

5.2 Limitations

Efficiency and from factor are concerns with the proposed array antenna. We need to make improvements to these parameters for microstrip patch antennas in order to make them more useful for 5G applications.

5.3 Future Work

As we can see from the previous findings and simulation analysis, our proposed array antenna's from factors were all below average when compared to earlier research. More work may be done to minimize as a result. In order to test the overall performance of the planned and simulated antenna and to compare the results of the simulation and measurements, the antenna should also be built in the real world.

References:

[1] L. Smith, "What are 5G metals and why should investors take note? • Core Group", Core Group, 2021. [Online]. Available: https://www.coreconsultantsgroup.com/what-are-5g-metals-and-why-should-investors-take-note/

[2] “Wireless terrestrial communication; cellular telephony”, Ariel Pashtun. Aware networks, Eolss publishers, Inc. 2006

[3] "Cellular Mobile | BTRC", [Online]. Available: http://old.btrc.gov.bd/cellular-mobile.

[4] S. Bhandarkar and R. Kammar, "4G TECHNOLOGY", ResearchGate. [Online]. Available: https://www.researchgate.net/publication/309535876_4G_Technology.

[5] "What Is 5G? - How Does 5G Network Technology Work", Cisco. [Online]. Available: https://www.cisco.com/c/en/us/solutions/what-is-5g.html#~faqs.

[6] "Comparison of 2G 3G 4G 5G | 2G vs 3G vs 4G vs 5G | Rantcell", Rantcell.com. [Online]. Available: https://rantcell.com/comparison-of-2g-3g-4g-5g.html.

[7] Hussain, Niamat & Jeong, Minjoo & Abbas, Anees & Kim, Tae-Jun & Kim, Nam. (2020). A Metasurface-Based Low-Profile Wideband Circularly Polarized Patch Antenna for 5G Millimeter-Wave Systems. IEEE Access. PP. 1-1. 10.1109/ACCESS.2020.2969964.

[9] "Global update on spectrum for 4G & 5G", Qualcomm.com, 2020. [Online]. Available: https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/messaging_presentation_-_4g_5g_spectrums_-_december_2020.pdf.

[10] "Antenna Frequency Explained", MP Antenna. [Online]. Available: https://www.mpantenna.com/antenna-frequency/.

[11] S. Khillar, "Difference Between Bandwidth and Data Rate | Difference Between", Differencebetween.net.[Online].Available:http://www.differencebetween.net/technology/difference-between-bandwidth-and-data-rate/.

[12] "Impedance Matching: Formula, Circuit & Applications", www.electrical4u.com, 2021.

[13] D. Schweber, "Understanding Antenna Specifications and Operation", www.digikey.be, 2017. [Online]. Available: https://www.digikey.be/nl/articles/understanding-antenna-specifications-and-operation.

[14] "Antenna Theory - Radiation Pattern", Tutorialspoint.com. [Online]. Available: https://www.tutorialspoint.com/antenna_theory/antenna_theory_radiation_pattern.htm.

[15] M. M. M. Ali and A. Sebak, "Directive antennas for future 5G mobile wireless communications," 2017 32th General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Montreal, QC, 2017, pp. 1-4.

[16] J. SANKAR, "Antenna Polarisation - Electronics For You", Electronics For You, 2016. [Online]. Available: https://www.electronicsforu.com/technology-trends/learn-electronics/antenna-polarisation.

[17] M. Pandian and T. Chinnadurai, "Design and Optimization of Rectangular Patch Antenna Based on FR4, Teflon and Ceramic Substrates", http://www.eurekaselect.com, 2019. [Online]. Available: http://www.eurekaselect.com/article/91521.

[18] A. Duvey, "Microstrip Antenna | Advantages, Disadvantages - Electronics Club Antenna & Wave Propagation", Electronics Club. [Online]. Available: https://electronics-club.com/microstrip-antenna/.

[19] W. Hong et al., "Multibeam Antenna Technologies for 5G Wireless Communications," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pp. 6231-6249, Dec. 2017.

[20] R. K. Goyal and U. Shankar Modani, "A Compact Microstrip Patch Antenna at 28 GHz for 5G wireless Applications," 2018 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering (ICRAIE), 2018, pp. 1-2, doi: 10.1109/ICRAIE.2018.8710417.

[21] A. Qayyum, A. H. Khan, S. Uddin, O. Ahmad, J. S. Khan and S. Bashir, "A Novel mmWave Defected Ground Structure Based Microstrip Antenna for 5G Cellular Applications," 2020 First International Conference of Smart Systems and Emerging Technologies (SMARTTECH), 2020, pp. 28-31, doi: 10.1109/SMART-TECH 49988. 2020. 00023.

[22] Z. Shuai and M. H. Sagor, "Wearable Finger Ring Antenna Array for 5G/mmWave Applications," 2019 IEEE International Conference on Telecommunications and Photonics (ICTP), 2019, pp. 1-3, doi: 10.1109/ ICTP48844 2019.9041740.

[23] Z. Lodro, N. Shah, E. Mahar, S. B. Tirmizi and M. Lodro, "mmWave Novel Multiband Microstrip Patch Antenna Design for 5G Communication," 2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), 2019, pp. 1-4, doi: 10.1109/ ICOMET .2019. 8673 447.

[24] G. Shivani, K. G.S., D. Santhoshi, D. R. Krishna and S. K. Koul, "Low cost 3D Printed dual band antenna for mm Wave 5G Applications," 2019 IEEE Indian Conference

on Antennas and Propogation (InCAP), 2019, pp. 1-4, doi: 10.1109/InCAP47789.2019.9134513.

[25] Z. Chen, J. Zhang, Z. Chen, B. Sun, S. Xu and C. Guo, "An Antenna in Package for 5G mmWave Application," 2020 21st International Conference on Electronic Packaging Technology (ICEPT), 2020, pp. 1-3, doi: 10.1109/ICEPT50128.2020.9202480.

[26] O. Darboe, D. Onyango Konditi and F. Manene3, "A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications", ResearchGate, 2019. [Online].

[27] Mungur and S. Duraikannan, "Microstrip Patch Antenna at 28 GHz for 5G Applications", Peacockscientificpubli cations.com, 2018. [Online].

[28] S. F. Jilani, Q. H. Abbasi and A. Alomainy, "Inkjet-Printed Millimetre-Wave PET-Based Flexible Antenna for 5G Wireless Applications," 2018 IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G), 2018, pp. 1-3, doi: 10.1109/IMWS-5G.2018.8484603.

[29] M. Vinoth and R. Vallikannu, "A compact triple slotted Rectangular Microstrip Patch Antenna with Metamaterial ground for Sub-6 GHz/5G communication," 2020 Fifth International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), 2020, pp. 34-38, doi: 10.1109/ICRCICN50933.2020.9296184.

[30] D. Liu, M. Zhang, B. Wang and J. Wang, "An Ultra-low-profile MIMO Antenna for 5G Smart-phones," 2018 International Symposium on Antennas and Propagation (ISAP), 2018, pp. 1-2.

[31]https://www.researchgate.net/publication/349461706_Design_and_Analysis_of_a_28 _GHz_Microstrip_Patch_Antenna_for_5G_Communication_Systems

[32] N. Supreeyatitikul, A. Phungasem and P. Aeimopas, "Design of Wideband Sub-6 GHz 5G MIMO Antenna with Isolation Enhancement Using an MTM-Inspired Resonators," 2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering, 2021, pp. 206-209, doi: 10.1109/ECTIDAMTNCON51128.2021.9425774.

[33] https://onlinelibrary.wiley.com/doi/abs/10.1002/mmce.23004

[34] Md Mohiuddin Soliman, Abu Zafar Md. Imran, Kazi Sami Ullah “Highly Efficient 2x2 Antenna Array at 28 GHz and 38 GHz for 5G Applications” International Conference on Inovation in Engineering and Technology(ICIET) 23-24 December, 2019.

[35] Md Mohiuddin Soliman, Mohammad Lutful Hakim, Engr. Mohammed Jashim Uddin, Muhammad Mostafa Amir Faisal, Atikur Rahaman, “Optimization of Design Parameters of

Microstrip Patch Antenna at 28 GHz and 38 GHz for 5G Application”. The 3rd IEEE International Conference on Telecommunications and Photonics (ICTP) 2019
[36] Dr.M. Kavitha, T. Dinesh Kumar, Dr.A. Gayathri, V. Koushick “28 GHz printed antenna for 5G communication with improved gain using array” International journal of scientific & technology research volume 9, issue 03, march 2020
[37] Kai da xu (member, ieee), han xu yanhui liu, (member, ieee), jianxing li and qing huo liu, (fellow, ieee) “Microstrip Patch Antennas with Multiple Parasitic Patches and Shorting Vias for Bandwidth Enhancement” IEEE Access (Volume: 6), page 11624 – 11633, 18 January 2018
[38] Z. Ahmed, P. McEvoy and M. J. Ammann, "Comparison of Grid Array and Microstrip Patch Array Antennas at 28 GHz," 2018 IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G), 2018, pp. 1-3, doi: 10.1109/IMWS-5G.2018.8484539.
[39] Km. Kamakshi, Ashish Singh, Mohammad Aneesh, and J. A. Ansari “Novel Design of Microstrip Antenna with Improved Bandwidth” International Journal of Microwave Science and Technology Volume 2014, Article ID 659592, 7 pages
[40] D. Imran, M. M. Farooqi, M. I. Khattak, Z. Ullah, M. I. Khan, M. A. Khattak and H. Dar, “Millimeter Wave MicroStrip Patch Antenna for 5G Mobile Communication” 2018 International Conference on Engineering and Emerging Technologies (ICEET), 22-23 Feb. 2018, 19 April 2018.
[41] Kai da xu (member, ieee), han xu yanhui liu, (member, ieee), jianxing li and qing huo liu, (fellow, ieee) “Microstrip Patch Antennas with Multiple Parasitic Patches and Shorting Vias for Bandwidth Enhancement” IEEE Access (Volume: 6), page 11624 – 11633, 18 January 2018.
[42] B. P. A. Mahatmanto and C. Apriono, "High Gain 4×4 Microstrip Rectangular Patch Array Antenna for C-Band Satellite Applications," 2020 FORTEI-International Conference on Electrical Engineering (FORTEI-ICEE), 2020, pp. 125-129, doi: 10.1109/FORTEI-ICEE50915.2020.9249810.
[43] D. Imran, M. M. Farooqi, M. I. Khattak, Z. Ullah, M. I. Khan, M. A. Khattak and H. Dar, “Millimeter Wave MicroStrip Patch Antenna for 5G Mobile Communication” 2018 International Conference on Engineering and Emerging Technologies (ICEET), 22-23 Feb. 2018, 19 April 2018

[44] https://www.semanticscholar.org/paper/Design-of-Rectangular-Patch-Array 1%C3 %972-MIMO-Antenna Nurrachman Hakim/ eeefcdd6cef38ad6479c78ded826cc59b a9c68ba

[45] G. M. Amrutha and T. Sudha, "Triple Band Antenna for 5G Applications," 2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2018, pp. 1650-1652, doi: 10.1109/ICACCI.2018.8554784.

[46] R. Parthasarathy, A. Chandrasekar and P. G. V Ramesh, "Design of Linear 2 × 2 Array Using Substrate-Integrated-Waveguide Patch Antenna for 28GHz mm-Wave Applications," 2019 TEQIP III Sponsored International Conference on Microwave Integrated Circuits, Photonics and Wireless Networks (IMICPW), 2019, pp. 44-49, doi: 10.1109/IMICPW.2019.8933228.

[47] S. S. Kim, S. H. Kim, J. H. Bae and Y. Joong Yoon, "Series Chained Patch Phased Array Antenna for mmWave 5G Mobile in Metal Bezel Design," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, 2019, pp. 279-280, doi: 10.1109/APUSNCURSINRSM.2019.8888629.

[48] T. H. Le et al., "Compact Wideband Antenna-in-Package Based on PCB Technology for 39 GHz 5G mmWave Applications," 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022, pp. 1-4, doi: 10.23919/EuCAP53622.2022.9769323.

[49] I. Ndip, T. H. Le, O. Schwanitz and K. -D. Lang, "A comparative analysis of 5G mmWave antenna arrays on different substrate technolgies," 2018 22nd International Microwave and Radar Conference (MIKON), 2018, pp. 222-225, doi: 10.23919/MIKON.2018.8405183.

[50] https://www.indeed.com/career-advice/career-development/research-methodology

[51] https://www.3ds.com/products-services/simulia/products/cst-studio-suite/

[52] R. Kingston, "Systems I: Radiometry, Communications, and Radar", 2022. [Online]. Available: https://www.sciencedirect.com/topics/engineering/reflected-power. [Accessed: 05- Sep- 2022].