BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

Design & Analysis of 5G Microstrip Patch Antenna at 5.8 GHz for 5G Communication.

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Dedication

This thesis work is dedicated to all of our honorable & respectable teachers and parents.

Candidates Declaration

My Thesis work name is Design & Analysis of 5G Microstrip patch Antenna at 5.8 GHz For 5G Communication. It is hereby that the work presented in this thesis work has not been submitted elsewhere for the award of any degree or diploma, does not contain any unlawful statement.

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Acknowledgements

In the name of Allah, the most merciful and the most gracious .All praises to Allah (SWT) for blessing us with abundant opportunities and giving His mercy and guidance to us throughout our lives. May the peace and blessings of Allah be upon the Prophet Muhammad (saw) who guides and inspires our lives. I express our warm happiness to our honorable Supervisor and Head, Dept. of ETE, IIUC Engr. Syed Zahidur Rashid for the initiative in this field of research. We are also thankful to Abdul Gafur, convener of our thesis for his dedication and sacrifice and we also express our gratitude to our friends, well-wishers, for their direct or indirect involvement in the completion of this thesis.

Abstract

In telecommunication, a microstrip patch antenna are becoming increasingly useful because they are also can be printed directly onto a circuit board. The thesis work present the performance of 5G Microstrip patch Antenna at Sub-6 GHz for 5G Communication. In our thesis work we define many parameter result in design Antenna. We design this antenna in CST software. We compare the performance of our design Antenna in another research work. The gain, return loss, VSWR and efficiency of our design antenna is 5.863db,-42.36db, 1.01 and efficiency 83%.

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Chapter 1

Introduction

1.1 Evolution of Wireless Communication

The more capable national PTTs concentrated their marketing efforts in the 1980s on extending the phone service to mobile users. The first public radio telephone nets, based on the cellular idea of frequency reuse, were introduced in the 1970s. Sweden, Norway, Denmark, Belgium, the Netherlands, Switzerland, and Austria all adopted variations of the Nordic Mobile Telephone system to provide more user capacity with better and automated services. All of these analog systems employ a frequency division multiple access protocol (FDMA). The system was initially implemented in the 450 MHz range and then expanded to include the 900 MHz frequency. Nearly a million people subscribed to the NMT system's different iterations by the end of the 1980s. In Great Britain, the analog Total Access Communication System (TACS) had over 750,000 customers by 1989. Around 165,000 people were customers of the Radiowoman network in France, while another 165,000 people were subscribers to the C450-network (NETZ-C) in Germany. In the US, there were 2 million users of the Advanced Mobile Phone System (AMPS) and American Radio Telephone System (ARTS) combined in 1988. In the early 1990s, the GSM digital cellular telephone network was launched in Europe in the 900 MHz range. Donald Cox came to the conclusion that the development of personal communication technology in the late 1980s followed two entirely different evolutionary paths: high-power automobile cellular mobile radio technology and low-power pedestrian and stationary cordless telephone technology.

1.2 Zero Generations Wireless Communication (0G)

Standard mobile telephony, such as PTT (Push to Talk), which offers a half-duplex system; MTS (Mobile Telephone Service-46-USA); and IMTS (Improved Mobile Telephone System), an improved variation of MTS that offers a full-duplex system, are the first steps in the evolution of communication. Other technologies used to enhance customer communication include OLT and AMTS (Advanced Mobile Telephone System). All of these 0G [6] technologies are first-stage ones that are now in use in the communications industry. After World War II, the 0G, often known as the Zero Era, in wireless communication made remote phone access possible. These mobile devices might not be able to handle the handover function, which involves changing the channel's frequency while moving between 0G, 1G, 2G, 3G, and 4G networks. The term "zero generation “Describes the early 1970s pre-cellular mobile system. For instance, before the invention of mobile phones, some subscribers had radio telephones in their vehicles. Modern cellular mobile phone technology was created by the mobile radio telephony system.

1.3 First Generations Wireless Communication (1G)

This was the initial generation of cell phone development. The first wave of commercial cellular networks was introduced in the late 1970s, and fully floating standards were established during the 1980s. Australia's first mobile phone network, utilizing analog 1G technology, was established in 1987 by Telecom, now known as Telstra. The first-generation, analog-based wireless telephone technology is referred to as 1G. They were known as "analog cell phones" when they first debuted in 1980. In 1979, NTT (Nippon Telephone and Telegraph) unveiled the first cellular system, which went into service in Tokyo, Japan. In Europe, the Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS) were the two most widely used analog systems. In addition to these two systems, an analog system was also introduced in Europe in the 1980s by another technological business. Cellular network systems' handover and roaming capabilities, on the other hand, were unable to function across national borders [5].The main drawback of first-generation mobile technology is the lack of international interoperability. Other issues with1G include its low capacity, inconsistent handoff mechanism, and weak voice connectivity. Furthermore, there was no protection because audio communications were replayed on Wi-Fi towers, leaving them open to unwanted parties. In the USA, AMPS, which debuted in 1982, was the first 1G standard. For this system, the 800-900 MHz frequency range has a 40 MHz channel that was assigned by the Federal Communications Commission (FCC). In 1988, AMPS received expanded spectrum (ES), an additional 10 MHz of capacity.

1G's distinguishing feature:

- 1G communication uses the frequencies of 800 MHz and 900 MHz
- There is a 10 MHz bandwidth.
- It uses analog switching as its technology.
- Frequency modulation is 1G's modulation mode (FM).

Fig 1.1:1G Communication System [11]

1.4 Second Generations Wireless Communication (2G)

The first significant improvement to cell phones came with the switch from 1G to 2G. The analog radio signals used by the 1G network 2 and the digital 2G networks distinguish the two mobile phone systems (1G and 2G). The primary goal of this generation was to establish a more dependable and secure route of communication. Many of the fundamental features we still use today were introduced by the technical leap from 1G to 2G, including SMS, internal roaming, conference calls, call hold, and service-based billing, such as long-distance call costs and real-time billing. Despite having flaws, the First Generation network persisted until 1991, when the Second Generation network took its place. This underutilized, flexible network utilized computerized signals rather than straightforward ones, greatly enhancing both security and capacity. 2G systems allowed users to send SMS and MMS messages at modest rates of up to 64 kbps thanks to transmission speeds ranging from 30 to 200 kHz. With the introduction of 2.5G, which allowed package exchange in the form of GPRS and EDGE, GSM technology continued to advance. And once GPRS was introduced in 1997, users could send and receive emails while out and about. The technological advance from 1G to 2G introduced many of the basic services we still use today, such as SMS, internal roaming, conference calls, call hold and service-based billing, e.g. charges based on long-distance calls and real-time billing.

Key feature of 2G:

Key features of the 1G system as
shown below-

- Digital system (switching)
- SMS services are possible
- It is possible to roam 18
- Enhanced safety
- Encrypted transmission of voice
- First internet with a lower data rate
- Disadvantages to the 2G system
- Low rate of data
- Limited mobility
- Less features for mobile devices

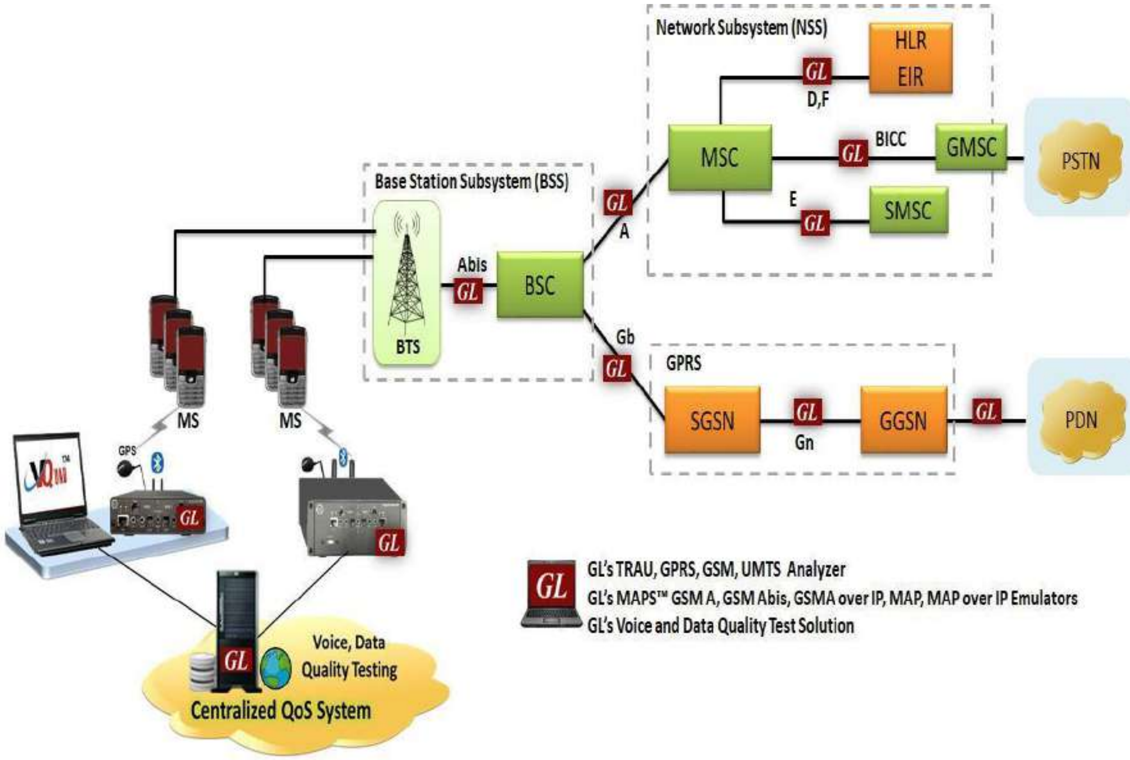

Fig 1.2: 2G Communication System [12]

1.5 Third Generations Wireless Communication (3G)

This generation raises the standard for wireless technology, which we have grown to love and know. Third-generation smartphone applications such as web browsing, email, video streaming, photo sharing, and others have been deployed. The objectives for third generation mobile communication, which was commercially introduced in 2001, were to offer a wider range of applications, encourage higher voice and data capacity, and enhance data transfer at a cheaper cost. Similar to 2G, 3G developed into 3.5G and 3.75G as additional features were added to bring about 4G. A 4G telephone may connect through a 3G or even 2G network, but a 3G telephone cannot do so. New generations of phones are nearly always built to be backwards compatible. The introduction of 3G, also known as UMTS in Europe and CDMA 2000 in the United States, in the year 2000 indicated a shift in how mobile phones were used and perceived by the end user, with less emphasis on voice conversations and more on social connections. in how mobile phones were used and perceived by the end user, with less emphasis on voice conversations and more on social connections bps. Customers may hold video conferences, access the internet, exchange files, and play online games, and even watch TV online thanks to 3G's ability to send larger amounts of data at faster speeds. While 3G networks might take anywhere from 11 to 90 seconds to download a 3minute MP3 song, 2G networks could do it in 6–9 minutes.

Key features of 3G system

Key feature of 3G system is given below

- High data rate
- Video calling
- Enhanced security, a greater number of users and coverage
- Mobile application support
- MMS support
- Tracking Location and maps
- Improved web browsing

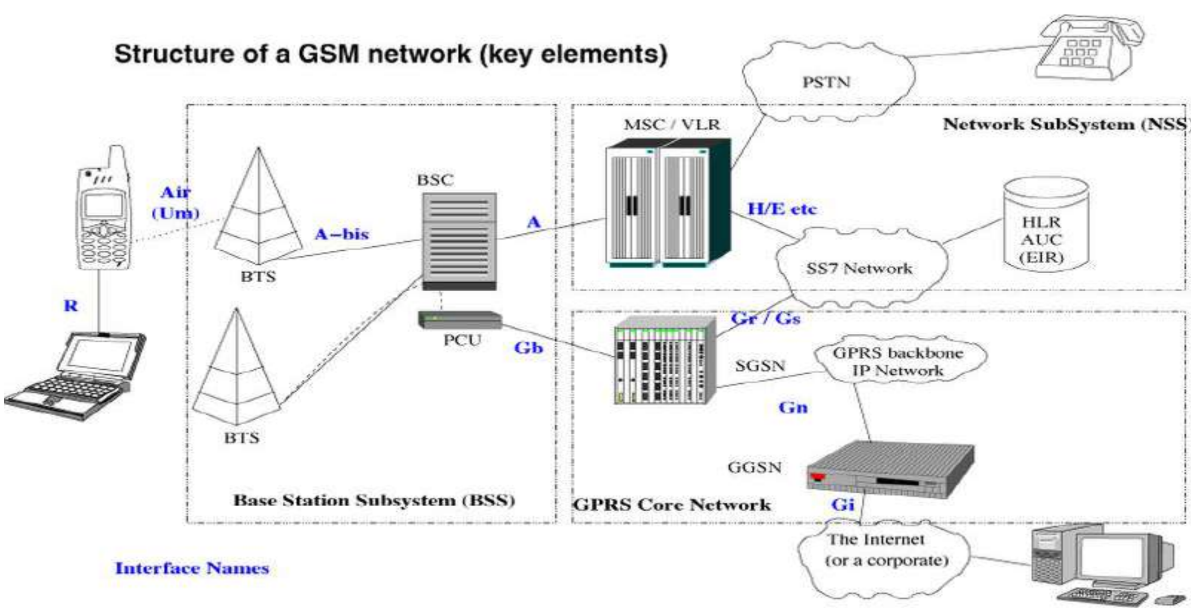

Fig1.3: 3G communication system [13]

1.6 Fourth Generations Wireless Communication (4G)

In comparison to 3G, 4G is a totally different technology, and it has only really been made available in the last 10 years. Its purpose is to provide high-quality, high-capacity, and internet over IP services to customers while strengthening security and bringing down the cost of those services. Examples of possible and present usage include enhanced mobile web access, IP telephony, gaming, high-definition mobile television, video conferencing, 3D TV, and cloud computing. MIMO (Multiple Input, Multiple Output) and OFDM were the main technologies that made this possible (Orthogonal Frequency Division Multiplexing). LTE and WiMAX are the two main 4G technologies, and LTE has seen extensive adoption (which has since petered out). Potential and existing applications include enhanced mobile web access, IP telephony, gaming, high-definition mobile television, video conferencing, 3D TV, and cloud computing. MIMO (Multiple Input Multiple Output) and OFDM (Orthogonal Frequency Division Multiplexing) are the main technologies that made this possible. WiMAX (have now fizzled out) and LTE (have seen widespread deployment) are the two relevant 4 G standards. LTE (Long Term Evolution) is a series of enhancements to current UMTS technologies that will be implemented on the existing 1800MHz frequency band of Telstra. The first IP-based mobile network, which includes telephony as a reasonable added benefit, is 4G. This organization, which might provide association for tablets, smartphones, and tablets, has to be supported by all portable devices released after 2013. Customers may value reduced idle time (less buffering), better call quality, quick access to social networking and moment-to-moment news, and high-quality spilling.

Key features of 4G systems

Key feature of 4G system is given below:

- Much higher data transmission rates up to 1 Gbps
- Improved security and agility
- Reduced potential for mission perilous applications
- HD video streaming and gaming
- Voice over LTE network VoLTE

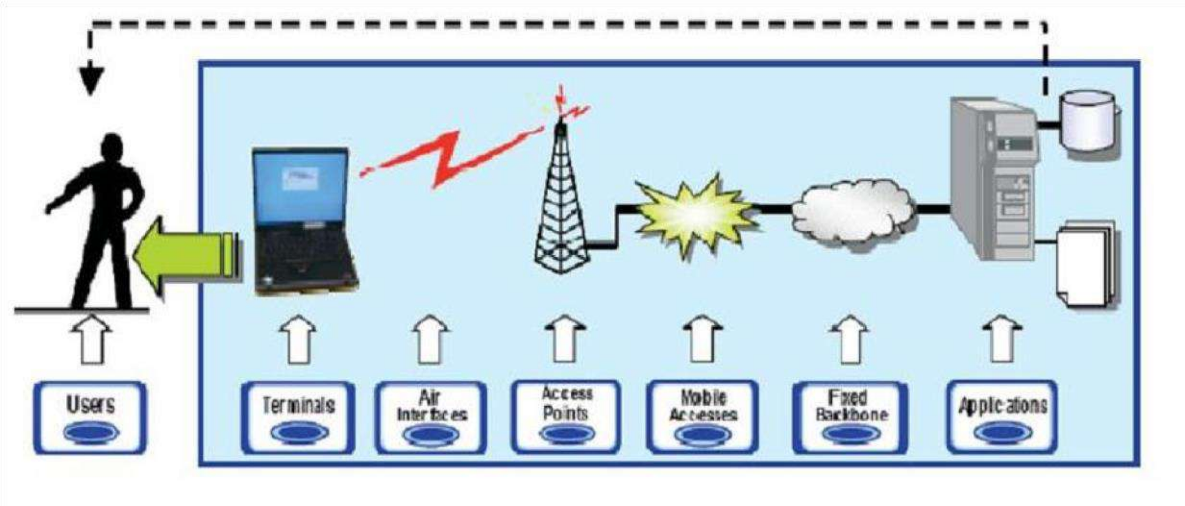

Fig1.4: 4G communication system [12]

1.7 Fifth Generations Wireless Communication (5G)

A technology called 5G is now being created to improve upon 4G. Among other improvements, 5G promises much greater data speeds, quicker connections, and lower latency. Some of the 5G concepts include communication between devices, larger batteries, and overall cellular coverage 3. More than 35 times faster than 4G, the maximum 5G speed target is expected to be around 35.46 Gaps. Watch out for emerging technologies like Large MIMO and Mobile Communications Millimeter Wave. Massive MIMO, millimeter wave, tiny cells, and Li-Fi are all recent technologies that might be leveraged to provide consumers with previously unheard-of 10 GB/s speeds and enable connections for at least 100 billion phones. For the day when the 5 G networks officially launches, several forecasts were made. Today, wired connectivity is all but obsolete. Currently, cell phones serve many more functions outside only being a means of communication. While earlier wireless technologies facilitated the ease of phone and data exchange, the fifth generation of wireless technologies is introducing a new level and transforming human existence into a true mobile life.

Key Features of 5G

Feature of 5G is given below

- 1 Gbps to 10 Gbps connections to end points in the field.
- Potential of 1ms
- 1000x bandwidth in per unit area.
- 10x to 100x number of linked devices.
- Availability is 99.999 percent.
- 100 percent coverage.
- 90 percent saving in system energy usage

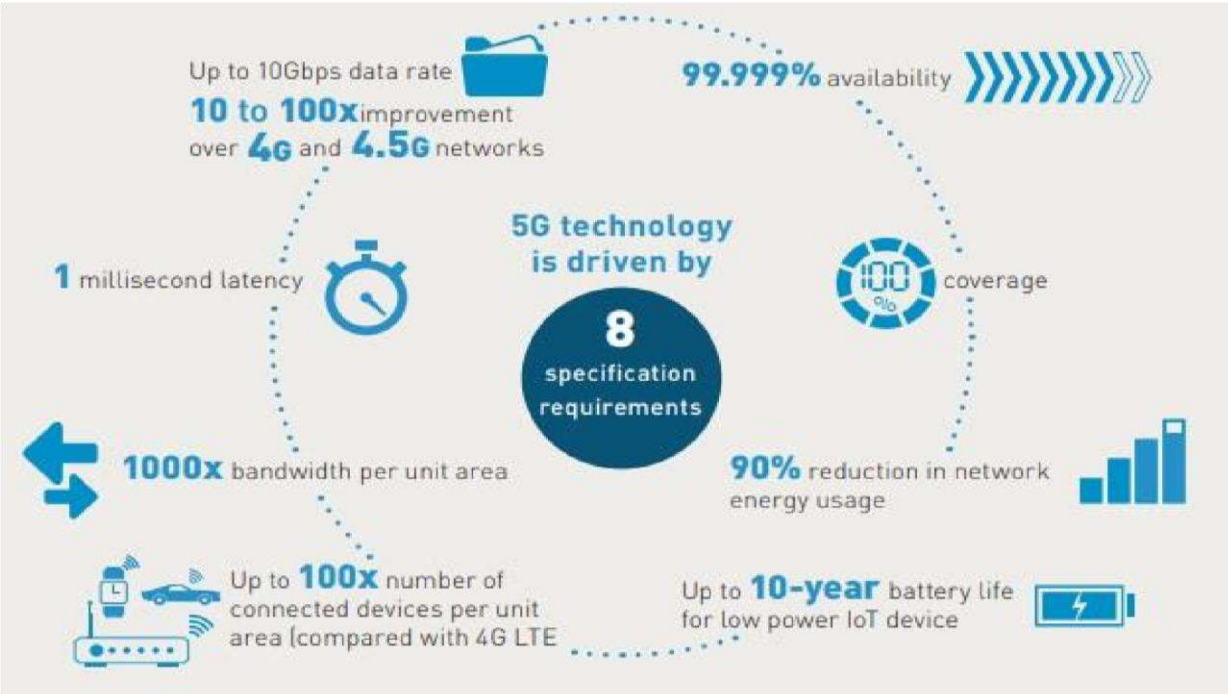

Fig 1.5: 5G communication system [13]

1.8 Update on 5G spectrum globally

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

	<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	

Fig 1.6: Global 5G Spectrum [14]

1.8.1 To enable 5G, the FCC is leading important spectrum measures

Across the low, mid, and high bands, including mm Wave

Fig 1.7: 5G spectrum [14]

1.8.2 The band of Low

1. After the assignment phase, a portion of the 600 MHz spectrum was profitably auctioned, generating $19.8 billion in earnings.

2. 70 MHz of licensed spectrum is divided into two channels, with an additional 14 MHz of unlicensed spectrum.

3. The time of spectrum utilization corresponds to 5G.

Generation	Speed	Technology	Time period	Features
1G	14.4 Kbps	AMPS, NMT, TACS	1970 – 1980	During 1G Wireless phones are used for voice only.
2G	9.6/ 14.4 Kbps	TDMA, CDMA	1990 to 2000	2G capabilities are achieved by allowing multiple users on a single channel via multiplexing. During 2G Cellular phones are used for data also along with voice.
2.5G	171.2 Kbps 20-40 Kbps	GPRS	2001-2004	Internet becomes widespread and data becomes more appropriate. Multimedia services and streaming starts to grow. Cell Phones started to support web browsing, though limited number of cell phones have that facility.
3G	3.1 Mbps, 500- 700 Kbps	CDMA-200 UMTS, EDGE	2004-2005	Supports multimedia services together with streaming. Worldwide access and movability across different types of device are made possible such as Telephones, PDA's etc.
3.5G	14.4 Mbps, 1-3 Mbps	HSPA	2006 – 2010	Provides higher throughput and speeds to support higher data
4G	100-300 Mbps. 3-5 Mbps 100 Mbps (Wi- Fi)	WiMax, LTE, Wi-Fi	Now (Read more on Transitioning to 4G)	Speeds for 4G are further increased to keep up with data access demand used by various services. High definition streaming is now supported in 4G. New phones with HD capabilities surface. It gets pretty cool. In 4G, Portability is increased further. World-wide roaming is not a distant dream.
5G	1-10 Gbps	Massive MIMO, Beamorming, mm wave	Soon (probably 2020)	Currently there is no 5G technology deployed. When this becomes available it will provide very high speeds to the consumers. It would also provide efficient use of available bandwidth [5].

TABLE 1.1 GENERATION OF COMMUNICATION [15]

1.8.3 The band of mid

Residents Broadband Radio Services

- In order to make PAL guidelines suitable for 5G, the FCC developed them in 2017.
- As a result of that endeavor, the CBRS Alliance, an LTE-based ecosystem, was formally unveiled.
- Inquiries about 3.7-4.2 GHz and 5.9-7.1 GHz were reported to the FCC.

1.8.4 The band of High

The 2016 and 2017 Second Spectrum Frontiers ruling

- It opens up numerous mm-wave bands at about 11 GHz.
- 70 percent of bands released recently are either unlicensed or shared.
- Taking into account the addition of 24.25-24.45, 24.75-25.25 GHz and 42-42.5 GHz

1.8.5 5G mm Wave bands are governed by spectrum boundaries. The shared and unlicensed airwaves are the keys to increased bandwidth.

Certified Spectrum

27.5 to 28.35 GHz 37.6 to 38.6 GHz

From 38.6 to 40 GHz

Unlicensed and shared spectrum

37.6-37.7 GHz

64 GHz-71 GHz

1.8.6 Spectrum of 5G in Europe

- The 3.4-3.8 GHz events and the 26 GHz events are both heavily auctioned in 2017 and 2018.
- In 2017–2018, Occam intended to auction a 150 MHz channel at 3.4–3.6 GHz, and in 2018– 2019, a 110 MHz channel at 3.6–3.8 GHz.
- The government of Ireland successfully auctioned off 350 MHz of frequency spectrum for 5G communication.

- In 2018, the Spanish government proposed that to meet market demand and operator requirements, a frequency between 3.6 and 3.8 GHz is needed.
- Spain, concentrating on the 26 GHz band. For release in 2018, at least 1.4 GHz of bandwidth is available.

1.9 Antenna Basics

An antenna is a dedicated transducer which transforms radio-frequency (RF) fields into electrical energy or vice-versa. There are two basic types: the receiving antenna, that captures RF energy and delivers alternating current to the equipment, and also the transmitting antenna, that is fed with electrical energy from the equipment and produces radio-frequency field. In wireless applications, the foremost common variety of antenna is that the microstrip patch antenna, used for wireless communications. Microstrip patch antennas are usually sensible solely at microwave frequencies.

1.9.1 Frequency

Frequency mainly are essentially the number of times an event occurs over a specific period of time. "The number of repetitions of a signal during a specific time period (1 second) is known as frequency," reads the standard definition. Frequency is a word used in engineering to describe the frequency of oscillatory and vibratory phenomena, such as radio waves, audio signals (sound), mechanical vibrations, and light. Heinrich Hertz, a German scientist, gave the unit of frequency hertz in the SI (International System) (Hz).

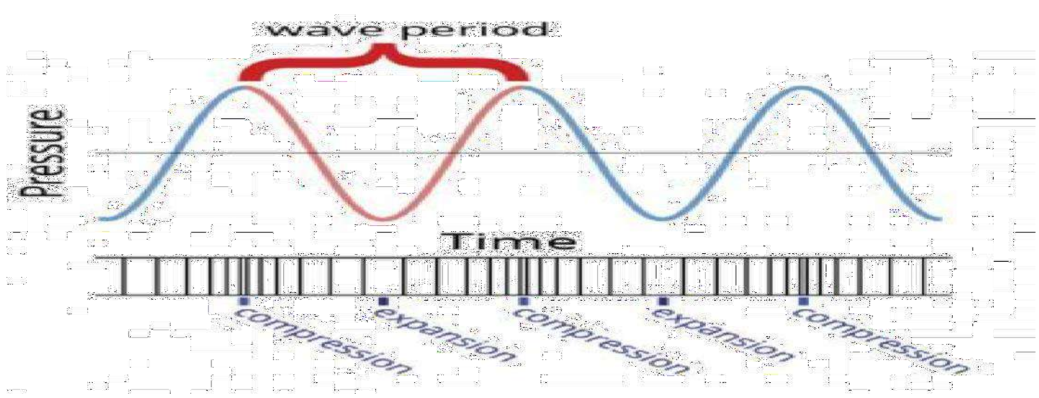

Figure 1.8: Frequency diagram [16]

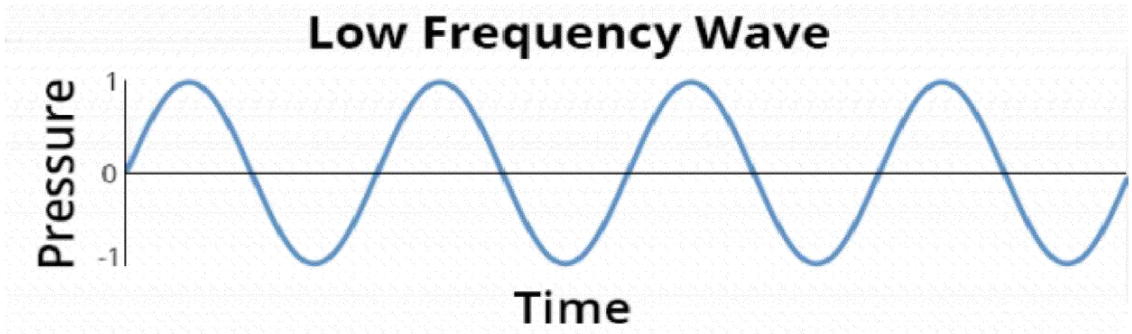

Fig1.9: Frequency wave [16]

1.9.2 Bandwidth

The ability of a wired or wireless communications system link to transmit the most data possible from one place to another through a computer network or internet connection in a predetermined length of time, usually one second, is referred to as bandwidth in communication systems.

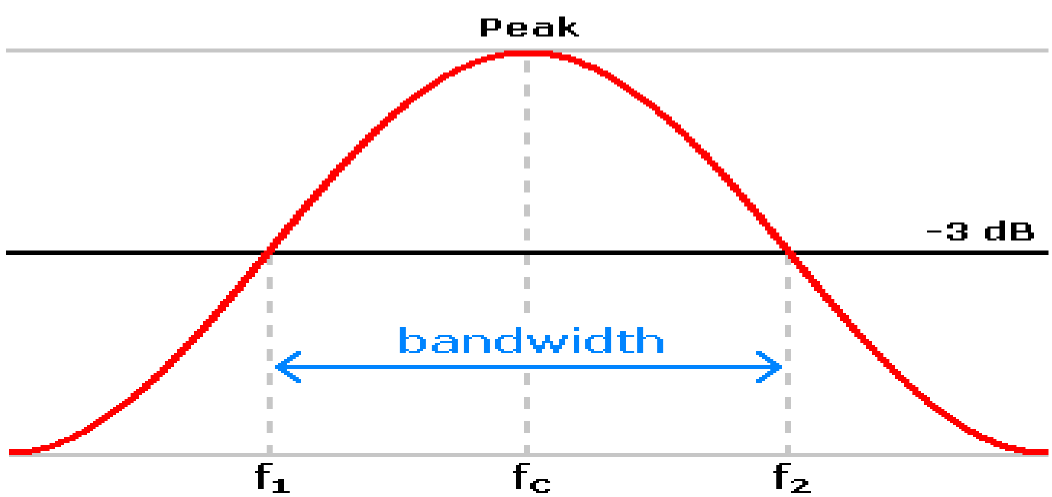

Fig1.10: Bandwidth [17]

1.9.3 Input Impedance

The voltage current ratio are mainly Input impedance is defined as such an antenna's input terminals. Input impedance are very important to an antenna which is mainly expresses the resonance of the antenna. It have mainly 2 parts: real and imaginary. The power that is radiated away from or absorbed by the antenna is represented by the real component of the input impedance. The reflected power imaginary fraction of the input impedance represents the energy stored in the antennas near field.

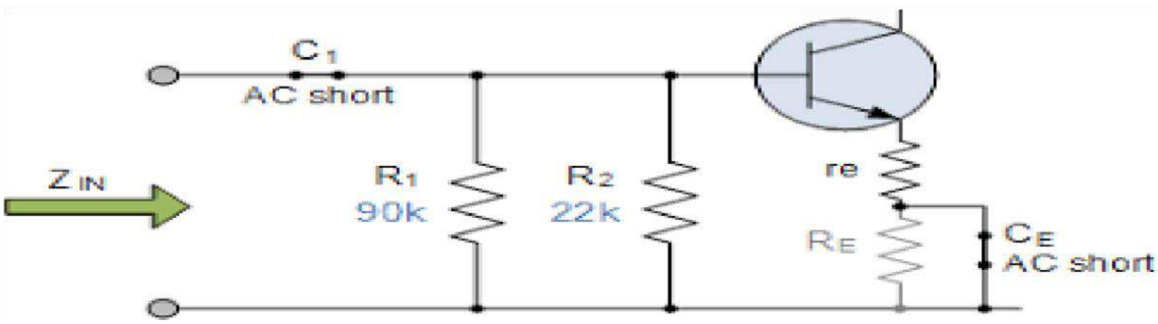

Fig 1.11.Impedence [18]

1.9.4 Directivity and Gain

In this session we know about the term of directivity which is describe an antenna’s ability to broadcast in an energy to more certain direction and to more receive. The main difference between the power produced by a hypothetical lossless isotropic antenna and the power produced by the antenna from a far-field source on the beam axis that is equally sensitive to all signal directions which is known as gain. Gain and directivity are conception that are connected.

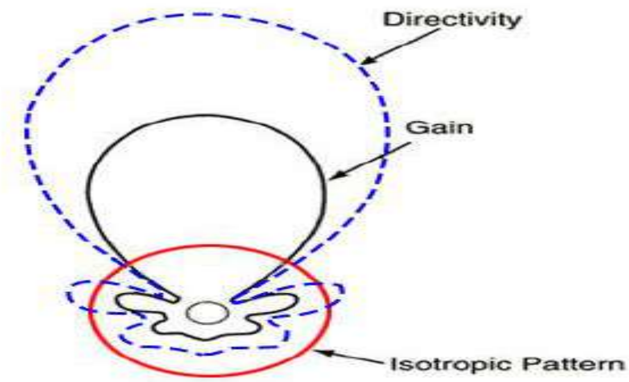

Fig 1.12: Gain [19]

1.9.5 Radiation Pattern

The term radiation pattern, commonly known to as antenna pattern or long field pattern, in the field of antenna design, describes the directional (angular) dependence of the frequency of the radio waves from the antenna. The radiation pattern is the term used to describe the relative strength of the field that is radiated by the antenna in different directions at a specific distance. The radiation pattern is also referred to as a "reception pattern" since it represents the characteristics of the antenna's receptor.

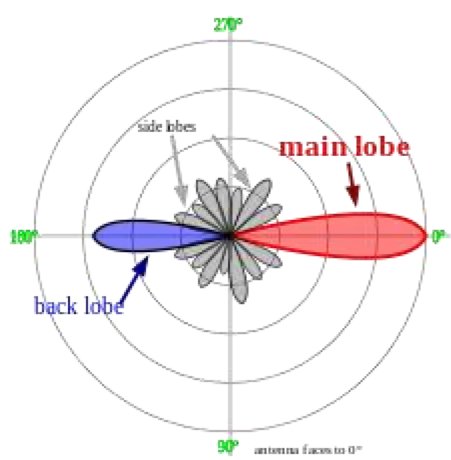

Fig 1.13: Radiation pattern [19]

1.9.6 Voltage Standing Wave Ratio (VSWR)

Voltage Standing Wave Ratio (VSWR) is a technique used to determine the efficiency with which radio-frequency power is carried from a power source via a load and down a transmission line. In other words, the standing wave ratio—also known as the highest power to minimum wave power ratio—can be determined (SWR). VSWR is the voltage ratio between the incident and reflected voltages. A true and positive antenna value is the VSWR.

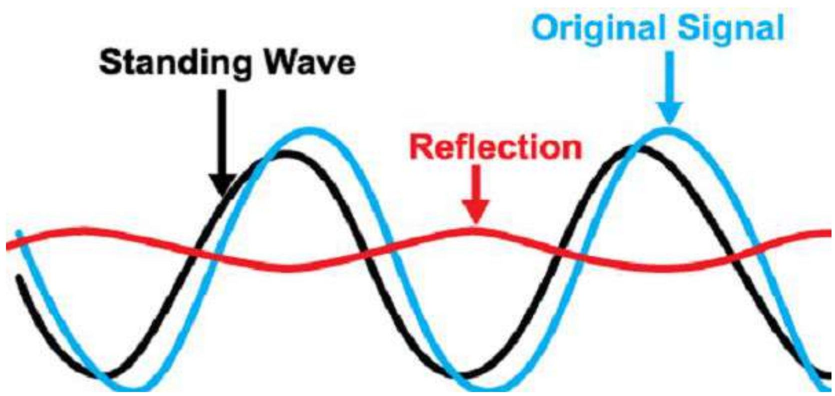

Fig 1.14: VSWR [20]

1.9.7 Return Loss (RL)

The ratio of radio waves arriving the antenna input and being accepted to those that are rejected is measured as the antenna's return loss. In terms of a short circuit, it is expressed in decibels (dB) (100 percent rejection). The mismatch between the antenna and the feed line is known as return loss (RL). The algorithmic ratio, which is measured in decibels (dB), contrasts the power provided by the transmission line with the power output by the antenna. The VSWR and RL are intimately connected.

1.10 Microstrip Antenna

A dielectric substrate with a ground plane on the other side and a radiating patch on one side is what makes up a microstrip patch antenna. The patch can have any form and is often constructed of conductive materials like copper or gold. The radiating patch and the feed lines are typically photo etched on the dielectric substrate. The term "patch antenna" refers to the most popular form of microstrip antenna. It is also feasible to use patches as array constituents in antennas. A patch antenna is a narrowband, wide-beam antenna made by etching the pattern of the antenna elements onto metal traces that are adhered to an insulating dielectric substrate, such as a printed circuit board, and have a continuous metal layer adhered to the side that faces the ground.

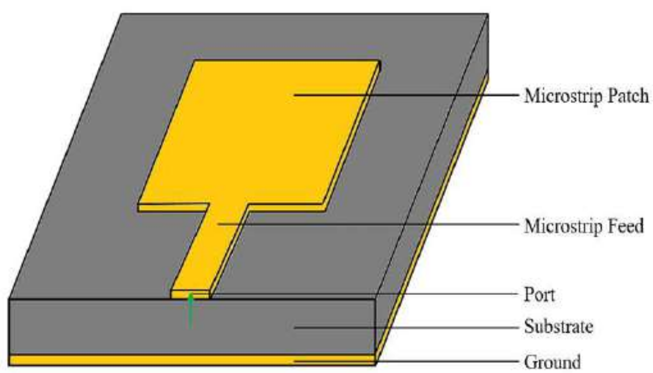

Fig 1.15: Microstrip patch antenna [21]

1.11 Microstrip Antenna Benefits and Drawbacks

Some Advantage of Microstrip Patch Antenna:

- Low manufacturing costs allow for large-scale production.
- Capable of operating on two and three frequencies.
- Simple microwave integrated circuit integration. Because of its reduced size, this antenna will work with smaller devices.
- Affordability and performance.

Some disadvantage of Microstrip Patch Antenna:

It provides a smaller gain. A tolerance issue that has a narrow bandwidth. It stimulates surface waves. Large ohmic losses in the array feed structure. The microstrip antenna's radiation mostly travels into half-space. It is less capable of managing power.

1.12 Antenna design tool

1.12.1 CST Microwave Studio

A high-quality tool for electromagnetic 3D high frequency simulation is CST Microwave Studio (CST MWS). CST MWS may be used to quickly and precisely analyze antennas, filters, couplers, planar and multi-layer structures, as well as SI and EMC effects. The program includes solvers for the time domain as well as solvers for the frequency domain. CST handles additional solver modules for specific purposes. Design possibilities are improved and time is saved by extracting SPICE parameters and importing filters for complicated CAD files. For electromagnetic design and analysis, CST provides more precise, effective computational solutions.

1.13 Motivation

Since the beginning of wireless communication, it has gained a lot of popularity due to its low cost, flexibility, portability, and several other qualities. Since the advent of wireless communication, it has grown in popularity due to its affordability, adaptability, portability, and many other qualities. Over the past three decades, there has been a sharp rise in demand for mobile connections, data rates, and mobile data traffic. They led to the development of the fifth generation (5G), which is designed to address needs for connection for more than 100 billion wireless devices, millisecond-level low latency, 10 Gbps data rates, and the internet of things, among other things. Early 2020 will see deployment [10]. The path-loss in high frequency is one of the main obstacles to the implementation of 5G, which inspired us to create an antenna that can overcome this difficulty.

Chapter 2

Literature Review

2.1 Overview of "Release 15 on 5G standard "Update by 3GPP:

The Third Generation Partnership Project (3GPP) unites [seven] organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC) that work to advance media communications standards and offers each of their employees an environment that is stable in which to deliver the reports and specifications that define 3GPP advancements. The 3GPP now controls the 5G standards. On the basis of the fulfillment of three essential performance factors, the International Telecommunications Union (ITU) has specified specific 5G specifications (KPIs).Peak data speeds of >10 Gbps for improved mobile broadband (eMBB).

2.1.1 Requirements of 5G:

It is essential to gather and agree on the framework's requirements in order to ensure that the right 5G remote system is created. By gathering the requirements, it is possible to determine the wants and develop the 5G remote system to satisfy the requirements and, in turn, satisfy desires. By agreeing on the requirements, all parties may work toward creating the same framework and finding solutions where their unique demands may not be fully addressed. In order to create the best framework possible, attention should be given to collect and properly study the 5G requirements. Something else, it appears, results in an unusable framework.

- Potential of 1ms
- 1000x per unit area bandwidth
- 10x to 100x number of linked devices.
- 99.999 percent availability
- Complete coverage.
- System energy usage is slashed by 90%

For the full version of Additional Radio to function properly, a significant quantity of new hardware must be installed (NR). It has been intended to continue utilizing the hardware as it is in phases. There are two versions: a freestanding (SA) version that uses an NR core and is completely free of the LTE core network, and an LTE core-based non-standalone (NSA) variant .

The operational frequency ranges suggested at the RAN4 conference in May 2018 are shown in Table 2.3. The fact that band n261 has been introduced is significant, as has the removal of band n259, which was formerly known as the Time Division Duplex (TDD) between 31.8 and 33.4 GHz). Initial designs for this band called for it to be a study band, however in November 2017, CEPT removed it from consideration for 5G. Such as 24.25 GHz to 29.5 GHz, are unquestionably being investigated for use in 5G NR. This recurring overhaul is adequately described in Specialized Report 38.815. Within the taking after recurrence chart is a higher visual representation of the frequencies of intrigued in various locations, obtained from that specific report. A huge amount of new hardware must be installed to correctly device the full version of New Radio (NR). A phased approach has been planned to carry on using current hardware. There are two versions: a non-standalone (NSA) version which will use the existing LTE core, and a standalone (SA) version which will use an NR core and it will be totally liberated of the LTE core network.

Metric	Requirement
Peak data rate	DL: 20 Gbps UL: 10 Gbps
Peak spectral efficiency	DL: 30 b/s/Hz UL: 15 b/s/Hz
User experienced data rate	DL: 100 Mbps UL: 50 Mbps
Area traffic capacity	Indoor hotspot DL: 10 $Mbps/m^2$
User plane latency	eMBB: 4 ms URLLC: 1 ms
Control plane latency	20 ms (encouraged to consider 10 ms)
Connection density	1M devices per km^2
Reliability	99.999% success prob.
Bandwidth	>100 MHz, up to 1GHz in > 6GHz

TABLE 2.1: TECHNICAL REQUIREMENTS OF 5G [22]

Technology	4G (LTE)	5G (NR)
Data Rates	Avg 25 Mbps Peak 300 Mbps	Avg 100 Mbps Peak 20 Gbps
Latency	~10- 50 ms	~ 1 ms
Mobility Support	Upto 350 Km/h	> 500 Km/h
Spectrum Efficiency	DL – 6 bits/Hz UL- 4 Bits/Hz	x3 Better DL- 30 bits/Hz UL- 15bits/Hz
Users Density	~ 2K / square Km	1000K/square Km
Energy Efficiency	Moderate	x100 Better

TABLE 2.2: DEFFERENCES BETWEEN LTE AND NR [22]

2.2 Paper Review

In this section we learn and comparison to another work to our work by reviewing many satisfaction publication.

1. A Sub-6GHz 5G Communication Slotted Ground Plane High Gain Microstrip

In this paper they work a slotted ground plane microstrip patch antenna in sub-6 GHz for 5G application. Their antenna's ground plane slot with a c shape .They enhance their antenna performance and modified the c slot. Their antenna's primary lobe of the emitted signal is good strong by conjecturing the side lobes.

2. Design of Patch Antenna for 6 GHz 5G Communication with WLAN Application (WRC-23):

This paper design a microstrip patch antenna having size of 26×24×1.6mm3 and the substrate is FR4 (ϵr = 4.4). Basically for the enhancement of data rate more spectrums have been introduced for multiple applications by using 5G technology. Our proposed antenna fulfills the requirement of one frequency band whose operating frequency is 6 GHz. The reflection coefficient |S11| is -21.16 dB with peak gain is 3dB.

3. Design and Characterization of a Slot based Patch Antenna for Sub-6 GHz 5G Applications:

In this paper they present the design, fabrication and characteristics of a dual band microstrip patch antenna. In their design's antenna the operating frequency is 3 GHz and 3.3 GHz. We know this is type of sub6 GHz. They use substrate of roger's 5880 with a permittivity of 2.2 and thickness is 1.57 mm. When they simulate their antenna the return loss value is -20.6 dB in 3 GHz frequency and -18.2 GHz in 3.3 Ghz.

4. A compact triple slotted Rectangular Microstrip Patch Antenna with Metameterial ground for Sub-6 GHz / 5G communication:

In this paper they design antenna which is operator in Sub-6 GHz application. Their resonant frequency is 3.13 GHz. The design antenna they modified PRA with MTM ground exhibits resonance at 3.27 GHz. Finally, their design antenna good concurrence between simulated and tested result are also presented to prove the functioning in their proposed antenna design.

5. A Wideband Kanji Patch Antenna for 5G Sub-6-GHz Applications:

In this paper they present the design, fabrication and characteristics of a dual band microstrip patch antenna. In their design's antenna the operating frequency is 2.3 GHz and 4.2 GHz. Their directivity are good .Their proposed antennas cannot cover several under used frequency band.

6. An Antenna with such a Circular Patch for Sub-6 GHz Applications:

This paper presents a four-element dual-band multiple-input, multiple-output (MIMO) antenna based on a co-axial probe fed microstrip circular patch. At 3.72 GHz and 4.35 GHz, the suggested antenna resonates. The conventional circular patch antenna has a greater resonance frequency. A g/2 slot is added to the ground plane to create the lower one. By adding simple arc-shaped slots to the ground plane, the port isolation at the lower frequency is improved (better than 15 dB). ECC value drops within accepted limits. The design is simple since the proposed MIMO antenna may be used to create a large one-dimensional array.

7. A multi-slotted antenna for LTE/5G Sub-6 GHz wireless communication applications:

In this paper they present the design, fabrication and characteristics of a dual band microstrip patch antenna. In their design's antenna the operating frequency is 3.15 GHz and 5.5 GHz. We know this is type of sub6 GHz. They use substrate of roger's 5880 with a permittivity of 2.2 and thickness is 1.59 mm. When they simulate their antenna the return loss value is -20.9 dB in 3 GHz frequency and -3.15 GHz in 5.5 Ghz.

8.5G Communication using a Small Square Patch Antenna:

The research is focused on the creation of a tiny microstrip antenna (MSA) for communicating signals in the sub-6GHz spectrum of 5G communication, specifically in the 3.4-3.6GHz region. A square microstrip patch antenna with a shorting pin is printed on the RT droid substrate in this study. Coaxial feeding is used to feed it. The square slot is erased off the patch, and the substrate thickness is raised to boost bandwidth. For analysis, metrics such as return loss (dB), gain (dB), and radiation pattern are used. It is assumed that the proposed antenna functions in the intended frequency band.

3rd Chapter

3.1 Methodology

The systematic, speculative analysis of a set of methods related to a specific field of study is known as methodology. It combines the speculative examination of the range of methods and perceptions relating to a data division. Typically, it includes ideas like standard, hypothetical demonstrations, phases, and objective or quantitative exploration methodologies. One may define strategy as a collection of tools or methods. This phrase may be used to refer to sharpens that are often used throughout a sector or a regular instruction, or the methods applied in a certain ask about ponder almost. Nevertheless, a method is not the same as a technique because it is not intended to provide answers. A methodology deals with the hypothetical justification for figuring out whether set of processes or technique can be practical in a certain situation.

3.2 Research Design

A technique created to find answers to the questions under investigation is the investigation plan. A work plan keeps track of a research project's resources, including its research address, autonomous and subordinate components, exploratory approach, and, if necessary, data collection strategies and a plan for factual investigation. Ask about design in relation to this question.

- A research on the transition to 5G
- A research on the 5G antenna needs pick the millimeter wave band for 5G.
- Check out the available 5G antennas and the literature on Dual Band MIMO antennas.
- Design of a Dual Band MIMO Antenna Examine the procedure for designing antennas in the CST Microwave Studio.
- Conduct the necessary calculations to create an antenna.

- Learn about the ideal substrate material. Identify the ideal substrate height. Find the most effective feeding method. Apply the procedure.

3.3 Plot Study

A pilot study is a research idea that has lately surfaced in the expecting idea. Pilot considerations often take place on a lesser scale than those for aiming. The chance of making a Sort I or Sort II error is decreased by a pilot's consideration, even if it cannot completely avoid all precise errors or frightening concerns. The majority of people view both types of errors as a waste of effort, time, and money.

1.3.1 Importance of Pilot Study:

There are many important of a pilot study before implementing the main study. Here are a few good reasons:

- To put the inquiry about preparing and/or convention to the test. These are regularly alluded to as possibility thoughts since the pilot thought tests how conceivable the plan is in reality.
- To recognize factors of intrigued and choose how to operationalize each
- To test a mediation methodology and recognize the components that are most imperative to the assistance of the mediation.
- To test methodological changes to usage or organization of an instrument and/or prepare work force on the organization of disobedient.
- To create or test the adequacy of investigate disobedient and conventions.
- To assess the measurable parameters for upcoming tests If there are any true contrasts to be detected, some factual investigations demand that the test measure be sufficiently large and inconsistent to distinguish differences between groups.

3.4 Software

Software is a set of instructions and data that directs a computer how to function. Unlike physical machinery, which is utilized to build the framework and does the task. Every piece of data produced by computer frameworks, counting programs, and knowledge of computer science and program design is referred to as a computer program. A computer program consists of computer programs, libraries, and related non-executable files, including online help or digital media. Both computer hardware and software are essential for operation; one cannot function properly without the other.

3.4.1 CST Software:

The high-performance 3D electromagnetic (EM) investigation software suite CST Studio Suite is used to develop, assess, and enhance EM parts and structures. In a single client interface, CST Studio Suite offers electromagnetic field solutions for applications in the EM spectrum. The solvers may be used by engineers to do half breed recreations, which enables them to investigate whole frameworks made up of several components in a useful and visible way. EM recreation may be included into the plan stream and drives development management from the very beginning thanks to code signing with others. The execution and prod are two popular EM research topics.

3.5 Objective of Research

1. To design a microstrip patch antenna in CST Studio Suit in Sub-6 GHz.
2. To validate the simulated antenna by comparing with existing antennas in various literature.

3.6 Design Procedure

- Step 1: First, based on Microstrip patch antenna, design an antenna which working frequency is 5.6GHz.
- Step 2: Using various feeding methods to find the right one based on the 5G criteria now.
- Step 3: For the design of 5.6 GHz antennas, the best feeding method, substrate height, and substrate material also were applied.
- Step 4: Save the antenna simulation and the structure.
- Step 5: Save the outcome if the conditions are met by the antenna
- Step 6: For better performance, optimize the built-in Microstrip patch antenna.

- Step 7: Save the antenna simulation and the structure.
- Step 8: Save the outcome if the conditions are met by the antenna. Step 9: Compare the outcome with the current antennas

3.6.1 Antenna Design by Equation

The first step in the antenna design is to choose the right dielectric substrate with the appropriate thickness (h). Dielectrics. Are used for electrical and mechanical stability changes. They are used to reduce the size of the antenna and help generate displacement current, which in the Magnetic Field (Ampere's Law) in turn generates varying time. In turn, this time varying Magnetic Field will generate time varying Electric Field (by the law of Faraday) and an electromagnetic propagating field is formed. In this way, the substrate can improve the radiation capability of the antenna. The dielectric constants of the substrates of the table above are comparatively high, which indicate high loss for designing antenna with elevated benefit. The Rogers RT Duroid 5880 material with a dielectric constant close to 2.2 is selected for this design because the purpose of this study is to design a multiband patch antenna. Then it is appropriate to pick the material on the microstrip line and the field. We have three options in this case: Copper, Silver or Gold. More conductive than the others, Silver is. The cost of copper, however, is far more complex and cheaper than the other two. Thus, copper is commonly used.

Patch width is given by,

$$w = c\ 2fr \ \sqrt{}\ 2\ \varepsilon r+1 \tag{3.1}$$

Where, c = Velocity of Light (3 × 108 ms -1)

Effective dielectric constant is given by,

$$\varepsilon\, eff = \varepsilon r+1\ 2 + \varepsilon\, r-1\ 2\ (1 + 10hw) \tag{3.2}$$

Where, εeff= Effective dielectric constant,= Dielectric constant of substrate, h = Height of dielectric substrate, w = Width of the patch.

For a given resonance frequency fr,

The effective length is given by,

$$62\ Leff = c\ 2fr\varepsilon eff \tag{3.3}$$

the actual length of the patch is given by,

$$L = L\ eff - \nabla L \tag{3.4}$$

Where, $\nabla L = 0.412h\ (\varepsilon r{+}0.3)\ (wh\ {+}0.268)\ (\varepsilon r{-}0.258)\ \ (w\ h\ {+}0.8)$

3.7 Antenna Design:

We design this antenna at 5.8 GHz frequency which is a sub-6 type frequency. We use FR4 lousy material to design our antenna. Our design Antenna the Antenna length is 35 and Antenna Width is 35.Subtance thickness is 1.57.Our design antenna metal thickness is 0.035.

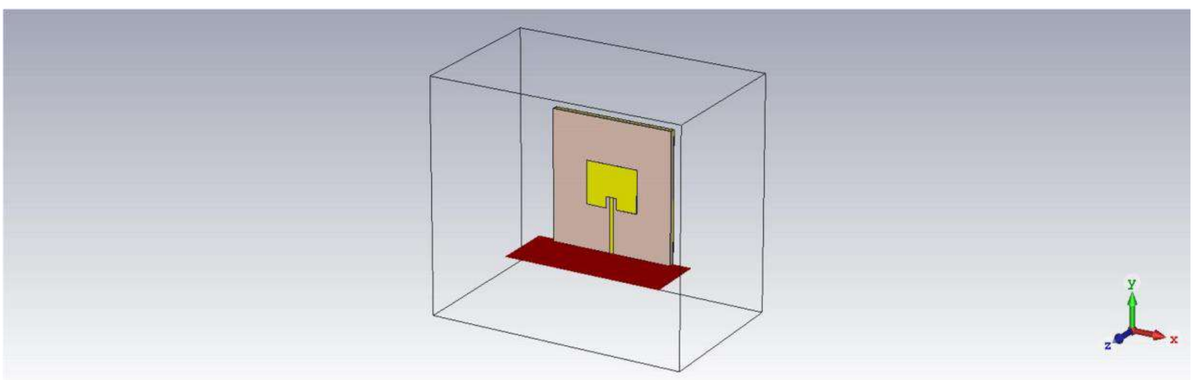

Fig 3.1: Design Microstrip Patch antenna’s Front view.

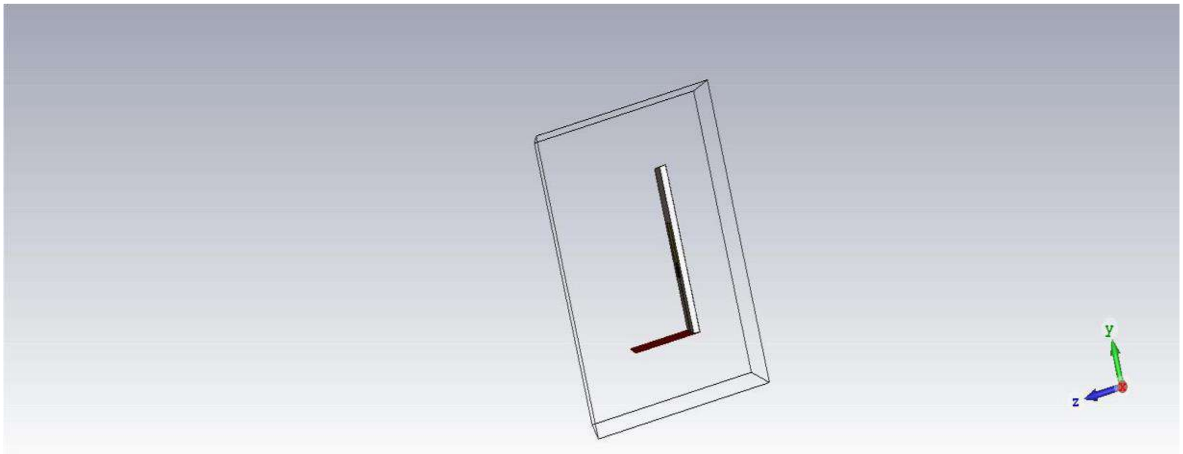

Fig 3.2: Design Microstrip Patch antenna’s side view.

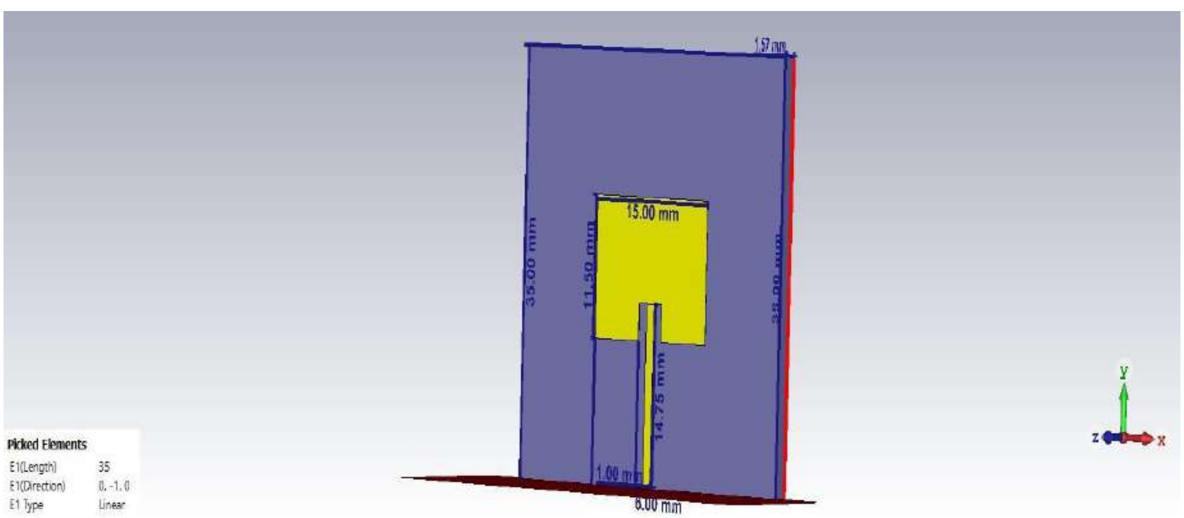

Fig 3.3: Design Microstrip Patch antenna’s parameter view

4th Chapter- Simulations and Results' Analysis

4.1 S11 parameter:

S-parameters (or scattering parameters**)** are used to describe how energy can propagate through an electric network. S-Parameters are used to describe the relationship between different ports, when it becomes especially important to describe a network in terms of amplitude and phase versus frequencies, rather than voltages and currents. S-Parameters are used to show a complicated network as a simple black box, and to easily present what happens to the signal in that network. In our design antenna s parameter value is -42.36 which is better than other research result

.

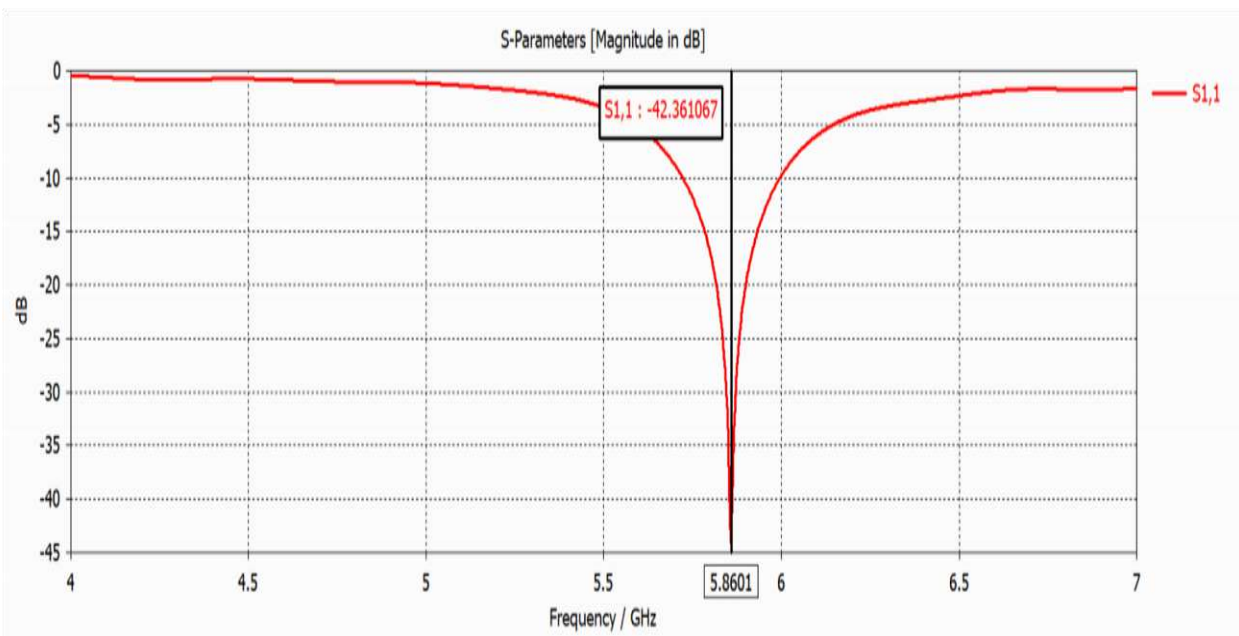

Fig 4.1: S parameter

4.2 VSWR

Voltage Standing Wave Ratio (VSWR) is a measurement of the efficiency of radio-frequency power transmission from a power source to a load through a transmission line (for example, from a power amplifier through a transmission line to an antenna).In our design antenna VSWR value is 1.01.

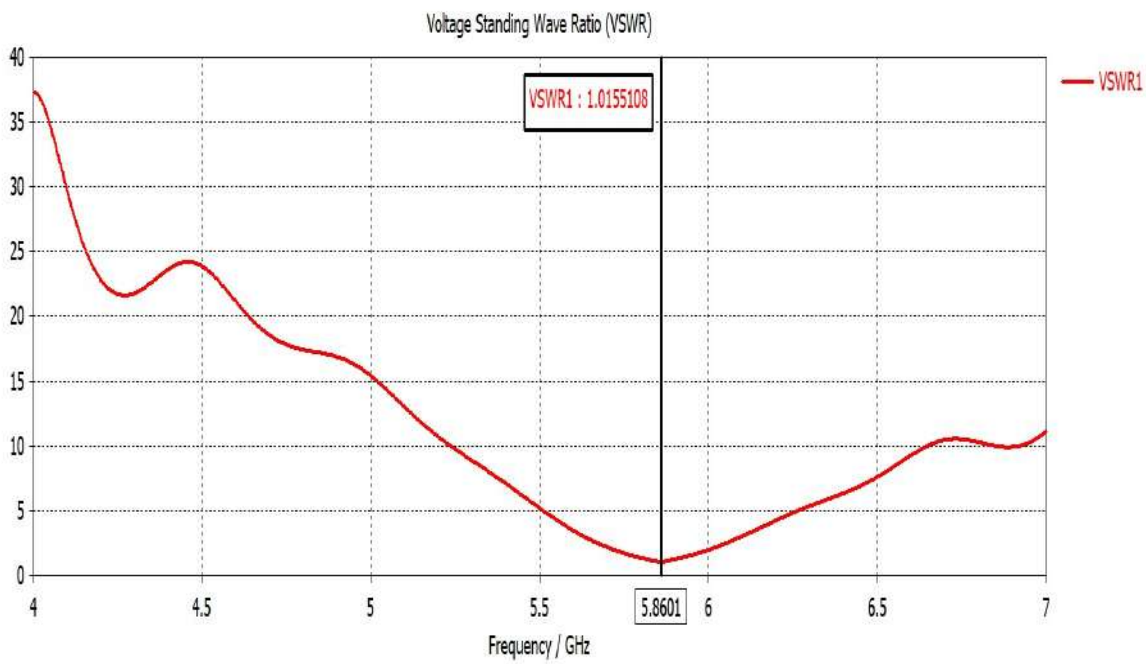

Fig 4.2: VSWR

4.3 Directivity

In electromagnetics, the directivity of an antenna or optical system is a metric that quantifies how much of the radiation emitted is focused in a single direction. It is the ratio of an antenna's radiation intensity in one direction to its overall average radiation intensity. The directivity of the hypothetical isotropic radiator is thus 1 or 0 db. The value of our antenna directivity design is 7.53.

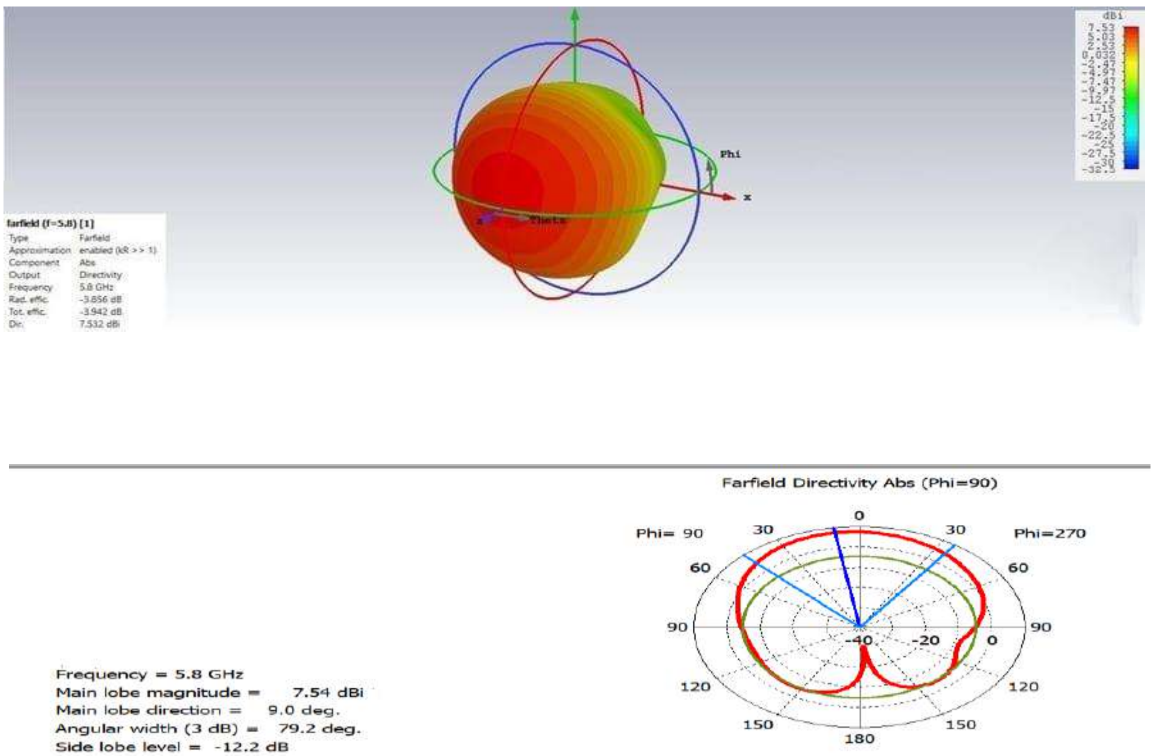

Fig 4.3: Directivity

4.4 Gain

Antenna gain is the ability of the antenna to radiate more or less in any direction compared to a theoretical antenna. If an antenna could be made as a perfect sphere, it would radiate equally in all directions. Such an antenna is theoretically called an isotropic antenna and does not in fact exist. The value of gain in our design antenna is 6.16.

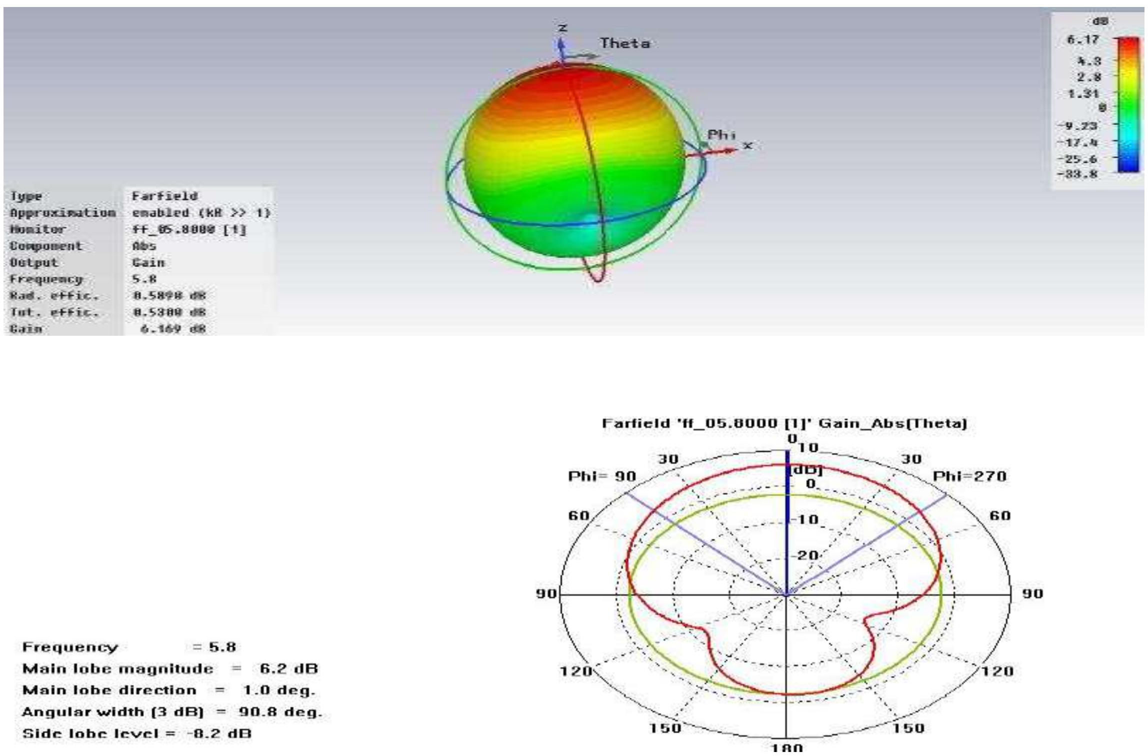

Fig 4.4: Gain

4.5 Efficiency

The literal definition of antenna efficiency is that it is "the ratio of the antenna's radiated power to its input power absorbed by the antenna."

Succinctly summarized, an antenna's purpose is to radiate electricity from its input with the fewest possible losses. The effectiveness of an antenna describes how well it can transmit its output with the fewest transmission line losses.

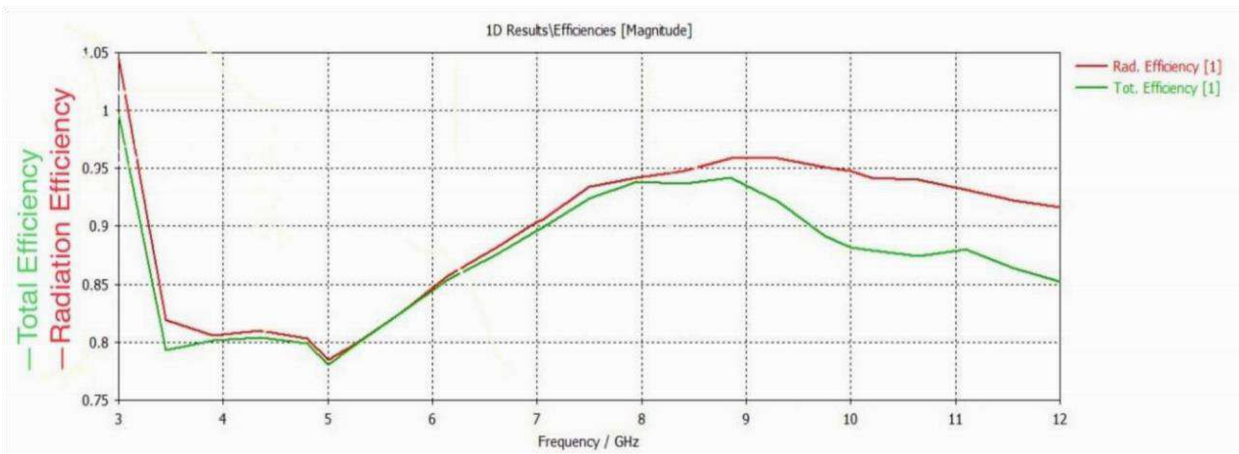

Fig 4.5: Efficiency

4.6 Parameter Description

We use a 5.8GHz resonant frequency in the construction of our antenna. We use the poor FR4 dielectric. FR4dielectrit is the most often used PCB laminate. The dielectric substance FR4 has the greatest research on it. This dielectric is used in the PCB design of an antenna. The antenna substrate length and substrate breadth values in our design are 35 and 35, respectively. The number for antenna width is 15. 11.5 is the antenna length value. Our intended substrate thickness for the antenna is 1.57.

Name	Expression	Value	Description	Type
Y	= 35	35	Substrate Length	Undefined
X	= 35	35	Substrate Width	Undefined
w	= 15	15	Antenna width	Undefined
SubT	= 1.57	1.57	Substrate Thickness	Undefined
MW82	= 1	1	Transmission line weidth	Undefined
MlineW	= 2.8	2.8	50 Ohm Microstrip line	Undefined
MetT	= 0.035	0.035	Metal Thickness	Undefined
l	= 11.5	11.5	Antenna Length	Undefined

Fig 4.6: Parameter list

4.7 Comparison Table

Reference	S11(dB)	VSWR	Directivity(dB)	Gain (dB)	Efficiency(dB)
[1]	-30.7	1.05	5.2	5.76	75%
[2]	-20.62	1.20	N/A	5.76	N/A
[3]	-22.99	1.59	5.87	6.28	80%
[4]	-35.47	1.37	N/A	5.5	N/A
[5]	-40.75	1.44	7.01	5.31	81%
Design Antenna	-42.36	1.01	7.53	6.169	83%

4.8 Result Analysis

Our designed antenna operates at 5.8 GHz. The S11 parameter value of our developed antenna is -42.36 dB, which is comparable to previous research. S11 is a measure of the power reflected by the antenna. 1.01 is the VSWR value. A measurement of the intensity of mismatch between an antenna and the feed line connected to it is the voltage standing wave ratio (VSWR). .Directivity is the ability of an antenna to concentrate radiation on a certain plane. Gain, on the other hand, refers to an antenna's capacity to transform input power into radio waves in a certain plane. The Voltage Standing Wave Ratio (VSWR) is an indication of the amount of mismatch between an antenna and the feed line connecting to it. By definition, directivity is the ability of an antenna to focus the radiation to a particular direction, whereas, the gain is the ability of the antenna to convert the input power into radio waves in a particular direction. Our value of Gain and Directivity is 6.169 dB and 7.532 db. Our efficiency almost 83%.

5th Chapter

Conclusion

The next main point for connection and smartphones is undoubtedly 5G connectivity. However, the idea of 5G connectivity as a whole has generated a lot of uncertainty. An individual microstrip antenna is made up of a ground plane made of metal foil on one side of the printed circuit board and a patch antenna made of metal foil in a variety of forms on the surface of the board. They can be applied to a variety of things, including mobile radios, wireless communications, satellites, missiles, spacecraft, and airplanes. Microstrip antennas also have the advantage of being easy and cheap to produce. Direct printing of these low-profile antennas onto a circuit board is an option.

Achievements

In this thesis, we improve the sub-6 GHz antenna performance from previous research work. We choose the ideal value for the s11 parameter, VSWR, and efficiency based on prior research. The simulated antenna's VSWR is less than 1.01 over the whole frequency band, maintaining the requirement that it remain between 1 and 2. The proposed antenna has a return loss of under 10 dB and operates at 5.8 GHz. The simulated antenna has an efficiency of about 85%.

Future work

To test how well the planned and simulated antenna performs in practice and to compare the simulation's output with measurements, the antenna needs also be built. By using high-quality substrate materials, such as low temperature ceramics, antenna losses (conduction and dielectric losses) will need to be reduced in the future. Co-fired Low dielectric and conduction losses on a ceramic substrate get the benefit of increasing efficiency.

Reference

[1] Vinoth, M. and Vallikannu, R., 2022. A compact triple slotted Rectangular Microstrip Patch Antenna with Metamaterial ground for Sub-6 GHz/5G communication.

[2] Amjad, Q., Kamran, A., Tariq, F. and Karim, R., 2019. Design and Characterization of a Slot based Patch Antenna for Sub-6 GHz 5G Applications. 2019 Second International Conference on Latest trends in Electrical Engineering and Computing Technologies (INTELLECT),

[3] Venkateshkumar, U., Kiruthiga, S., Mihitha, H., Maheswari, K. and Nithiyasri, M., 2020. Multiband Patch Antenna Design for 5G Applications. 2020 Fourth International Conference on Computing Methodologies and Communication (ICCMC).

[4] Abhishek, A. and Suraj, P., 2021. Design of Patch Antenna for 5G Communication at 6 GHz (WRC-23) With WLAN Application. 2021 6th International Conference for Convergence in Technology (I2CT),

[5] Olawoye, T. and Kumar, P., 2020. A High Gain Microstrip Patch Antenna with Slotted Ground Plane for Sub-6 GHz 5G Communications. 2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD).

[6] Abirami, M., 2017. A review of patch antenna design for 5G. 2017 IEEE International
Conference on Electrical, Instrumentation and Communication Engineering (ICEICE).

[7] Mahfouz, A., Shams, S., Elsaadany, M. and Gagnon, G., 2021. Safety Metrics Investigation of an Electrically Coupled Patch Antenna for sub-6 GHz Portable Devices Serving 5G/6G Systems. 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI).

[8] Gao, X., Zhang, L., He, Y., Zhang, L., Li, W., Wong, S. and Liao, C., 2020. A DualPolarized Compact Patch Antenna for Sub-6 GHz 5G Base Stations. 2020 IEEE AsiaPacific Microwave Conference (APMC).

[9] Jiang, J. and Li, Y., 2020. A Wideband Kanji Patch Antenna for 5G Sub-6-GHz Applications. 2020 13th UK-Europe-China Workshop on MillimetreWaves and Terahertz Technologies (UCMMT).

[10] Abhishek, A. and Suraj, P., 2021. Design of Patch Antenna for 5G Communication at 6 GHz (WRC-23) With WLAN Application. 2021 6th International Conference for Convergence in Technology (I2CT).

[11] Muhammad Ikram; Rifaqat Hussain; Mohammad S. Sharawi, "4G/5G antenna system with dual function planar connected array," in IET Microwaves, Antennas & Propagation, Volume: 11, Issue: 12, Aug. 2017.

[12] D. Sarkar, K.V. Srivastava, "Compact four-element SRR-loaded dual-band MIMO antenna for WLAN/WiMAX/WiFi/4G-LTE and 5G applications," in ELECTRONICS LETTERS 7th Vol. 53 No. 25 pp. 1623–1624 Dec. 2017.

[13] http://wiki.cas.mcmaster.ca/index.php/3G_Communication.

[14]https://www.researchgate.net/figure/The-global-snapshot-of-5G-spectrum_fig1_38870949

[15] Muhammad Ikram;Emad Al Abbas;Nghia Nguyen-Trong;Khalil H. Sayidmarie;Amin Abbosh, " Integrated Frequency-Reconfigurable Slot Antenna and Connected Slot Antenna Array for 4G and 5G Mobile Handsets", in IEEE Transactions on Antenna and Propagation, Vol. 67, Issue: 12, July 2019.

[16] Mohammad Mehdi Samadi Taheri;Abdolali Abdipour;Shuai Zhang;Gert Frølund Pedersen, "Integrated Millimeter-Wave Wideband End-Fire 5G Beam Streerable Array and Low-Frequency 4G LTE Antenna in Mobile Terminals", in IEEE Transactions on Vehicular Technology, Vol. 68, Issue: 04, Feb. 2019.

[17] http://www.differencebetween.net/technology/difference-between-bandwidth-and-data-rate/

[18] Emad Al Abbas;Muhammad Ikram;Amin Abbosh, "Dual Functional MIMO Antenna System for mmWave 5G and 2 GHz 4G Communications", in 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Oct.2019.

[19] https://www.everythingrf.com/community/what-is-antenna-directivity

[20] https://teltechinsight.blogspot.com/2020/10/what-is-voltage-standing-wave-ratiovswr.html

[21] https://www.everythingrf.com/community/what-is-antenna-directivity

[22] Rahayu, Yusnita, Rahayu and Muhammad, “Design of 28/38 GHz Dual-Band Triangular Shaped Slot Microstrip Antenna Array for 5G Applications” 2018, 2nd International Conference on Telematics and Future Generation Networks , p 93-97.

[23] Rahayu, Yusnita Fitria, Lisma Hakiki and Yofan Kurniawan, “A new 2×4 array design of dual-band millimeter-wave antenna for 5G applications,” 2018 International Conference on Promising Electronic Technologies (ICPET). pp 1-4.

[23] M. S. Sharawi and M. Ikram, "Slot-based connected antenna arrays for 5G mobile terminals," 2018 International Workshop on Antenna Technology (iWAT) , Nanjing, 2018, pp. 1-3.

[24] Shen, Dongya Ma, Chaojun Zhang and Xiupu, “Substrate Integrated Gap Waveguide Circularly Polarized Slot Antenna,” 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, pp. 460-461.

[25] B. Xu et al., "Radiation Performance Analysis of 28 GHz Antennas Integrated in 5G Mobile Terminal Housing," in IEEE Access, vol. 6, pp. 48088-48101, 2018.

[26] Rashid, Syed Zahidur, Abdul Gafur, Aasim Ullah, Md Hossain, Sultan Shah Mamun, Md Majumder, and Qudrat-E. Alahi. "Maximum Power Design and Simulation for a Low Return Loss Wearable Microstrip Patch Antenna." In Towards a Wireless Connected World: Achievements and New Technologies, pp. 161-175. Springer, Cham, 2022.

[27] Barua, Soumen, Abu Zafar Md Imran, Md Emdadul Hoque Bhuiyan, Subrata Barua, Syed Zahidur Rashid, Abdul Gafur, and Md Razu Ahmed. "Highly efficient microstrip patch antenna for wireless gigabit alliance applications." Indonesian Journal of Electrical Engineering and Computer Science 26, no. 3 (2022): 1451-1459 .

[28] Islam, Md Tohedul, Abu Zafar Md Imran, Fahim Chowdhury, Md Nur Nobe Hridoy, Md Humayun Kabir, Abdul Gafur, and Syed Zahidur Rashid. "Design and Analysis of Multiband Microstrip Patch Antenna Array for 5G Communications." In 2022 International Conference on Innovations in Science, Engineering and Technology (ICISET), pp. 29-32. IEEE, 2022.

[29] Faisal, Mohammad, Abdul Gafur, Syed Zahidur Rashid, Md OmarFaruk Shawon, Kazi Ishtiak Hasan, and Md Bakey Billah. "Return loss and gain improvement for 5g wireless communication based on single band microstrip square patch antenna." In 2019

1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), pp. 1-5. IEEE, 2019.

[30] Hossain, Tanvir, Masud Parvez, Abu Zafar Md Imran, Mohammed Jashim Uddin, Abdul Gafur, and Syed Zahidur Rashid. "TeraHertz Antenna for Biomedical Application." In 2022 International Conference on Innovations in Science, Engineering and Technology (ICISET), pp. 42-45. IEEE, 2022.