BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

A Compact size mmWave multiband microstrip patch antenna design for 5G communication

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Dedication

This thesis work is devoted to all of our respectable teachers and parents for their immense support & prayers.

Acknowledgement

For the glory of Allah, the Most Forgiving, the Most Merciful. All thanks and glory belongs to Allah (SWT), who has provided us with a wealth of chances and showered us with His kindness and guidance throughout life. And may Allah's peace and blessings be upon His Prophet Muhammad (SAAS), who has been a source of wisdom and inspiration for us.

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Abstract

A “+” shape slotted tri-band microstrip patch antenna for 5G mm-Wave & V-band application is designed and addressed in this paper. The designed antenna can be performed 5G mm-Wave and V-band applications. The proposed microstrip patch antenna has a compact size rectangular shape structure of 5.02 mm × 4.03 mm with a simple geometrical structure. Rogers RT 5880 (lossy) with a dielectric constant of 2.2 is used as substrate in this antenna with a thickness of .499 mm. The designed antenna covers multi-band operation. It resonates at 36.72 GHz, 41.73 GHz & 49.89 GHz mm-Wave bands with gains 6.615 dB, 6.017 dB & 5.752 dB respectively. The preferred antenna is designed with the benefits of low cost, compact size, good gain & efficiency by using microstrip feeding techniques.

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List of Symbols

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

List of Abbreviations

RT	Duroid 5880
IEEE	Institute of Electrical and Electronic Engineers
LTE	Long Term Evolution
5G	Fifth Generation
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
FCC	Federal Communication Commission
SDR	Software Define Ratios
GSM	Global System for Mobile communication
3D	Three Dimension
2D	Two Dimension
VSWR	Voltage Standing Wave Ratio
WCC	Wireless Communication Centre
IE3D	Moment of Method Based EM Computer
CST	Simulator Technology
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor

Chapter 1
Introduction

1.1 Evolution of Wireless Communication

The evolution of mobile wireless communication systems various stages of advancement since the first-generation mobile network was introduced in the early 1980s. Mobile communication standards grew quickly to serve more users due to the enormous demand for additional connections globally [1].

The transfer of information between two or more places that are not physically linked is known as wireless communication, or simply wireless. The most widely used wireless technologies employ radio waves. The word "wireless" has appeared twice in the history of communications, each time with a somewhat different meaning. From around 1890 until the advent of the new word radio in 1920, it was largely used to describe the earliest radio wave sending and receiving technology, such as in wireless telegraphy. The phrase was reintroduced in the 1980s and 1990s primarily to identify digital gadgets that could connect wirelessly. Long-distance communications and other services are made available through wireless operations that are not practicable or possible to achieve through the use of cables [2]. Figure 1.1 depicts the development of communication. Let's examine the stages of wireless communication technology development for mobile devices.

1.2 Zero Generation Wireless Technology (0G)

After World War II, the first wireless phone technology, known as 0G or Zero Generation, became available. Mobile carriers put up the calls since there were few viable communication channels at the time. These mobile phones were unable to handle the handover feature, which involves changing the channel frequency while travelling. The term "zero generation" describes the early 1970s pre-cellular mobile system. Before the invention of mobile phones, for instance, some subscribers had Radio telephones in their vehicles. Modern cellular mobile phone technology was created by the mobile radio telephony system. Since they were the forerunners of the first generation of cellular telephones, these systems are known as 0G (Zero Generation) Systems. The technologies used in Zero Generation systems included Push to Talk (PTT), Mobile Telephone System (MTS), Improved Mobile Telephone Service (IMTS), Advanced Mobile Telephone System (AMTS), Norwegian Offending Land-Mobil Telephone

(OLT), Public Land Mobile Telephony (PLT), and Swedish Mobile Telephony System D. (MTD). Loggers, builders, realtors, and celebrities were among the system's users. Only voice communication was conducted using the communication system [3].

Figure 1.1 Evolution/Enhancement of communication [4].

1.3 First Generation Wireless Technology (1G)

The first-generation, analog-based wireless telephone technology is referred to as 1G. They were known as analog cell phones when they were first debuted in 1980. In 1979, NTT (Nippon Telephone and Telegraph) unveiled the first cellular system, which went into service in Tokyo, Japan. The two most popular analog systems in Europe were Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS). In addition to these two systems, an analog system was also introduced in Europe in the 1980s by another technological business. The handover and roaming capabilities of cellular network systems were not, however, able to function across national borders [5]. The primary drawback of first-generation mobile technology is the lack of international interoperability. Other issues with 1G include its low capacity, inconsistent handoff mechanism, and weak voice connectivity. Furthermore, there was no protection because audio communications were replayed in wifi towers, leaving them open to unwanted parties. In the USA, AMPS, which debuted in 1982, was the first 1G standard. For this system, the Federal Communication Commission (FCC) designated a 40 MHz channel in the 800-900 MHz frequency band. Expanded spectrum (ES), a second 10 MHz of bandwidth, was given to AMPS in 1988. The communication systems used in Italy, France, and the UK were RTMI, Radio-Comm, and YACS, respectively. The telecom standard known as C-450 has been accepted by West Germany, Portugal, and South Africa. The First Generation system, which replaced the 0G system, includes mobile radio telephones and such technologies as the Advanced Mobile Telephone System (AMTS), Mobile Telephone System (MTS), Push to Talk (PTT), and Improved Mobile Telephone Service (IMTS).

- ❖ Developed in the 1980s and completed in the early 1990s.
- ❖ Up to 2.4 kbps of data transfer speed is supported.
- ❖ A first-generation mobile system, the advance mobile phone system (AMPS) was originally released by the USA.
- ❖ Users are only allowed to make phone calls inside their own nation [5].

1.3.1 Key features (technology) of 1G system

The following list of 1G system's key attributes -

- ❑ Bandwidth: 10 MHz;
- ❑ Frequency: 800 and 900 MHz (666 duplex channels with bandwidth of 30 KHz);
- ❑ Technology : Analogue switching is the technology used; Modulation : Frequency modulation is the modality (FM);
- ❑ Mode of Service : Voice-only service mode;
- ❑ Access Technique : Frequency Division Multiple Access access method (FDMA).

1.3.2 Disadvantages of 1G system

There are a number of disadvantages to the 1G system, including the following:

- ❖ Limited user base and cell coverage;
- ❖ Poor voice quality due to interference;
- ❖ Poor battery life;
- ❖ Large mobile phones that are uncomfortable to carry; Less security (calls could be decoded using an FM demodulator);
- ❖ No roaming between similar systems [1].

1.4 Second Generation Wireless Technology (2G)

The Second-Generation wireless network, or 2G, was developed using 1990s-era digital technology. In 1991, 2G was launched in Finland. It offered features including the Multimedia Message System (MMS), SMS, and photo messages (MMS). Similar to 2G, digital encoding allows for the delivery of data in a way that only selected receivers can receive and decode it for text messages and audio signals. Greater security is offered by 2G for both transmitter and receiver. to multiplex and compress The CODEC (compression decompression algorithm) for digital signals is utilized in 2G. In the 2G system, digital multiple access was implemented using TDMA and CDMA. While CDMA gives each user a unique code to communicate over a multiplexed channel, TDMA separates signals into time slots. The Digital Enhanced Cordless Telecommunications (DECT) standard for portable mobile phones uses TDMA technologies such as the Global System for Mobile Communications (GSM), Personal Digital Cellular (PDC), IS-136, and iDEN. The first 2G system was GSM. It is the most well-liked mobile standard among all wireless mobile technologies and is used in around 212 nations worldwide. GSM technology, which enables consumers to use their mobile phones in several countries, was the first to establish international roaming between various mobile phone operators. Up to 8 calls per channel can be multiplexed in GSM using TDMA technology in the 900 MHz and 1800 MHz frequency bands. It transmits circuit switched data and speech signals at a rate of up to 14.4 kbps. In the USA, the FCC also put up for auction a fresh block of spectrum in the 1900 MHz range. This technology has undergone continuous improvement over the past 20 years to offer improved services. Based on the original GSM, certain additional technologies have been developed, leading to some sophisticated systems known as 2.5 generation (2.5 G) Systems [5].

1.4.1 Key features of 2G system

Key features of 1G system given below -

- Digital system (switching)
- SMS services is possible
- Roaming is possible
- Enhanced security
- Encrypted voice transmission
- First internet at lower data rate
- Disadvantages of 2G system
- Low data rate
- Limited mobility
- Less features on mobile devices
- Limited number of users and hardware capability [1].

1.5 GPRS (General Packet Radio Service) 2.5G

A mobile wireless standard known as 2.5G, which stands for "Second and Half Generation," was created in the interim between its predecessor, the second generation, and its successor, the third generation. The "General Packet Radio Services" are referred to as being "second and half generation." The data rate offered by GPRS ranges from peaking at 56 Kbit/s to peaking at 115 Kbit/s. It supports features including Wireless Application Protocol (WAP), Access Multimedia Messaging Services (AMMS), and internet features like email and World Wide Web (WWW) access. While conventional circuit switching for data transmission bills per minute of connection time, GPRS often charges by the megabyte of traffic sent [5].

1.6 Third Generation Wireless Technology (3G)

The third generation of wireless communication standards, superseding 2.5G and coming before 4G, is defined by the Telecommunications Standards Group (3G). The International Telecommunication Union (ITU) developed a strategy to make use of the 2000 MHz global frequency band, which will be able to support a single, universal wireless network standard. "International Mobile Telephone 2000" or "IMT-2000 Standard" is the name of the program. Three different types of CDMA 2000's multiple access technology exist: It is based on the Code Division Multiple Access (CDMA) technology and is suggested by North American wireless Telecommunication standards bodies. It has a 1.25 MHz channel width and speeds of up to 144 Kbps.

WCDMA (UMTS): In 2001, NTT Do Como introduced the world's first commercial WCDMA service, FOMA, in Japan. Wideband Code Division Multiple Access is the more technical term. It has a 5 MHz channel width and speeds of up to 2 Mbps.

TD-SCDMA: The Time Division Synchronous Code Division Multiple Access (TD-SCDMA) technology was suggested by the China Wireless Telecommunication Standards Group for use in 3G [5]. In order to continue that effort, the Third Generation Partnership Project (3GPP) developed a wireless system that meets the requirements of the IMT-2000 standards. In the year 2000, the third generation, or 3G, of wireless technology entered commercial use.

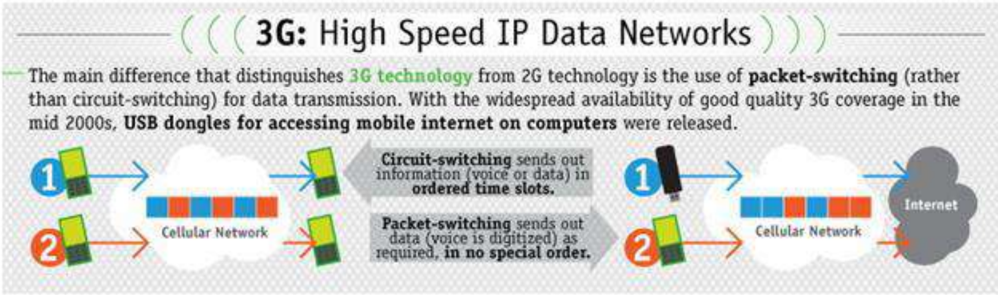


Figure 1.2: 3G vs 2G Communication [4]

The peak data transfer speed enabled by earlier technology was 144 Kbps, however 3G has upped it to 2 Mbps. To use 3G services, a smart phone or multimedia mobile phone is necessary. In order to enable web-based applications, audio, and video files, and conferencing totally in a portable wireless environment, 3G's bandwidth and data transmission rate were enhanced. Figure 1.2 compares communication across 3G and 4G. By increasing network capacity through improved spectral efficiency, network operators are able to provide their consumers with a wider variety of more modern amenities thanks to the adoption of 3G technology. Wide area wireless voice calls, video calls, mobile television, broadband wireless data, video, and GPS service are among the services offered by the 3G system. This network has advancements over the 2.5G network as earlier described below [5]:

- Data transmission speeds that are several times faster.
- Improved audio and video streaming.
- A video conference feature.
- Enhanced web and WAP surfing speed.
- Support for IPTV (TV over the Internet).

1.6.1 Key features of 3G system

Key feature of 3G system is given below -

- Higher data rate.
- Video calling.
- Enhanced security, a greater number of users and coverage.
- Mobile app support.
- Multimedia message support.
- Location tracking and maps.
- Better web browsing.
- TV streaming.
- High quality 3D games [1].

1.6.2 Disadvantages of 3G systems

The following are the disadvantages of the G system:

- ❖ Expensive spectrum licenses.
- ❖ Expensive infrastructure, equipment, and implementation.
- ❖ Increased bandwidth needs to handle higher data rates .
- ❖ Expensive mobile devices.
- ❖ Compatibility with frequency bands and older 2G systems [1].

1.7 Fourth Generation Wireless Technology (4G)

In order to provide high speed data transfer rates, such as 100 Mbps as the highest data rate fo r both the server and the data receiver who are travelling at a speed of 60 Kmph, the basic ide a behind 4G is interoperability between various kinds of networks. When the server and the receiver are stationary, the data transmission rate should not exceed 1 Gbps [5]. Figure 1.3 compares several generations of 4G smart phones.

4 Cell Phone Generations Compared

	Standards	Technology	SMS	Voice Switching	Data Switching	Data Rates
1G	AMPS, TACS	Analog	No	Circuit	Circuit	N/A
2G	GSM, CDMA, EDGE, GPRS	Digital	Yes	Circuit	Circuit	236.8 kbps
3G	UTMS, CDMA2000, HSPDA, EVDO	Digital	Yes	Circuit	Packet	384 kbps
4G	LTE Advanced, IEEE 802.16 (WiMax)	Digital	Yes	Packet	Packet	up to 1 Gbps

Figure 1.3: 4G cell phone generation compared [4]

In several countries, fourth generation (4G) mobile network standards have taken the role of third generation (2G) networks. In another situation, 4G is only a research project by academics that has had difficulty being implemented and capable of achieving its predetermined performance and throughput. With the use of numerous technologies, including Wi-Max, Wi-Fi, WAP, GPRS, EDGE, and Wi-Bro in 3G, we can now access the internet using our mobile phones. However, users encounter issues when they need to work in research labs to deal with 3G's restrictions and challenges. When using any of the aforementioned technologies to access the internet through a cell phone, users are stranded when they travel to locations where interoperability between various networks has been achieved. When using 4G, users may connect to the network using any of the aforementioned technologies even when they are moving from one location to another. The following concerns are ones that the 4G mobile network is said to have resolved:

- According to the fact that phones can send and receive large amounts of data quickly For increased security, 4G wireless technology has added an IP function to mobile phones.
- In the case of the fourth generation wireless standard, users can download at a speed of 100 Mbps for mobile access and 1 Gbps for local mobile network access while stationary.
- The hybrid technology used in 3G, which combined CDMA and IS-95, was replaced with a new technology called OFDMA in the 4G network. Compared to earlier TDMA or CDMA, OFDMA is more effective.
- An noteworthy characteristic of fourth-generation wireless systems is the use of OFDMA, in which data are conveyed by allotting the channel into a small band for increased efficiency.
- Wireless Mobile Broadband Access (WMBA), which is being developed by IEEE 802.16e, will be the definition in 4G. This suggests that the internet is accessible. The execution is being developed to prevent call interference in the event that data is downloaded from any website. The fact that 4G wireless technology will propose downlink data rates of 128 Mbps and uplink data rates of 56 Mbps is an extraordinary advancement. The service's shortcoming, the lack of a hotspot, is a requirement for internet access.
- LTE, a wireless technology for internet access, is expected to be included in 4G mobile phones concurrently with Worldwide Interoperability for Microwave Access (WiMAX). WiMAX and LTE are different from one another. LTE uses IP addresses and adheres to the TCP/IP model that was adapted from computer networking design. Along with fast data transferability, low latency, and bandwidth control, it will offer enhanced security. Since CDMA technology and 4G or LTE are both interoperable, data may be sent back and forth between the two networks.
- The two main wireless technologies that the 3GPP will introduce are LTE and IEEE 802.16m. A portion of the fourth generation wireless system has already been granted approval for additional processing. As of June 2009 [5], Version has approved IPv6 as a 4G wireless technology.

1.7.1 Key features of 4G systems

The following list of 4G system features is key:

- Up to 1Gbps, even faster data speeds.
- Increased mobility and security.
- Reduced latency for apps with a high priority.
- Streaming video in high definition and games.
- VoLTE, or voice over LTE, network (use IP packets for voice).

1.7.2 Disadvantages of 4G system

Following are some 4G system drawbacks:

- Expensive infrastructure and hardware.
- Pricey spectrum (most countries, frequency bands are is too expensive).
- It is necessary to use expensive, high-end mobile devices that are compatible with 4G technology.
- Widespread rollout and upgrading take time [1].

1.8 Fifth Generation Wireless Technology (5G)

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

In terms of mobile wireless technology, 5G is regarded as the pinnacle of wireless communication technologies. 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.

1.8.1 Features of 5G

The feature of 5G is as follows:

- 1–10Gbps connections to field end points.
- 1000x bandwidth per unit area with a 1ms latency.

- 10 to 100 times as many linked devices.
- 99.999 percent availability.
- Complete coverage.

System energy use is reduced by 90% [1].In the table below, the next generation of wireless communication technologies is summarized together with a look back at the last generation of wireless systems, which brings this section to a close. These new technologies have a long way to go in the coming years, and they will undoubtedly introduce fascinating and wonderful features [3]. Communication generation is displayed in Table 1.1.

TABLE 1.1 GENERATION OF COMMUNICATION

Generation	**Speed**	**Technology**	**Time period**	**Features**
1G	14.4 Kbps	AMPS, NMT, TACS	1970 – 1980	Wireless phones are only utilized for voice during 1G.
2G	9.6/ 14.4 Kbps	TDMA, CDMA	1990 to 2000	By enabling numerous users over a single channel through multiplexing, 2G capabilities are made possible. Cellular phones are utilized for both voice and data during the 2G era.
2.5G	171.2 Kbps 20-40 Kbps	GPRS	2001-2004	Internet usage increases, and data becomes increasingly relevant. Streaming and multimedia services are beginning to expand. Web surfing has been supported on mobile phones for a while, however not all of them have it.
3G	3.1 Mbps, 500-700 Kbps	CDMA-200 UMTS, EDGE	2004-2005	Supports streaming and multimedia services. Worldwide accessibility and portability across many device kinds, including phones, PDAs, etc., are made feasible.
3.5G	14.4 Mbps, 1-3 Mbps	HSPA	2006 – 2010	Greater speeds and throughput are offered to handle more data.
4G	100-300 Mbps. 3-5 Mbps 100 Mbps (Wi-Fi)	WiMax, LTE, Wi-Fi	Now (Read more on Transitioning to 4G)	To keep up with the demand for data access utilized by various services, 4G speeds have been further boosted. Streaming in high resolution is now possible over 4G. There are newly released HD-capable phones. It becomes rather chilly. The level of portability is raised with 4G. Traveling the world is not only a faraway fantasy.
5G	1-10 Gbps	Massive MIMO, Beamforming, mm wave	Soon (probably 2020)	There isn't any 5G technology in use right now. When this is made accessible, it will provide customers extremely fast speeds. Additionally, it would ensure effective use of the given bandwidth [5].

1.9 Final thoughts

To accommodate rising demand and more stringent specifications, wireless technology has been advancing rapidly. Since the introduction of first-generation mobile networks, the telecoms industry has had to deal with a number of brand-new challenges including technology, efficient spectrum utilization, and, most importantly, end-user security. Future wireless technologies will offer mobile networks that are incredibly fast, packed with features, and extremely secure [1].

1.10 Global 5G spectrum update

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	

Figure 1.4. Global 5G spectrum [6-7]

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

Across low-band, mid-band, and high-band including mmWave

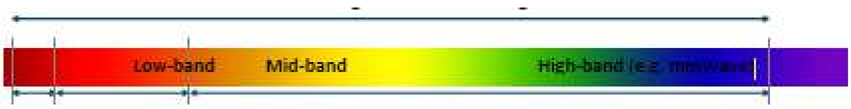


Figure 1.5 5G spectrum [6-7]

1.10.2 Low-band

Public auction: Broadcast Incentive

- ❖ After the assignment phase, a successful auction for a portion of the 600 MHz spectrum generated $19.8 billion in earnings.
- ❖ Two licensed channels totaling 70 MHz, with an additional 14 MHz for unlicensed usage.
- ❖ The period of spectrum availability coincides with 5G [6-7].

1.10.3 Mid-band

Residents Broadband Radio Services -

- Initializing a 150 MHz spectrum in the 3.5 GHz band with incumbents PAL1 and GAA2 in a 3-layer sharing arrangement.
- In order to make PAL guidelines compatible with 5G, the FCC developed them in 2017.
- The CBRS Alliance was formally launched in an effort to create an LTE-based ecosystem.
- The FCC alerted of inquiries on 3.7-4.2 GHz and 5.9-7.1 GHz. [6-7]

1.10.4 High-band

Spectrum Frontiers Ruling in 2016 & Second Ruling in 2017

- Opening up in multiple millimeter Wave bands about 11 GHz.
- Shared or unauthorized music makes up 70% of newly launched bands.
- Always in agreement. The FCC asked to be allowed to see another candidate spectrum designated for IMT-2020.
- Take into account including 24.25-24.45, 24.75-25.25, and 42-42.5 GHz. [6-7]

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

Key for more bandwidths are the shared and unlicensed spectrum.

Licensed Spectrum -

1. 27.5 GHz – 28.35 GHz
2. 37.6 GHz – 38.6 GHz
3. 38.6 GHz - 40 GHz

Shared and unlicensed spectrum -

1. 37 GHz– 37.6 GHz
2. 64 GHz- 71 GHz [6-7].

1.10.6 5G Spectrum in Europe

Strong focus on the mid-band (3.4 GHz–3.8 GHz) and the 26 GHz band (24.25-27.5 GHz) Key European Member States, including the EC RSC and CEPT, are driving regulatory initiatives to expedite the introduction of 5G in the EU.

1. With auctions expected to take place in 2017–2018, supervision of operations at 3.4–3.8 GHz and 26 GHz is particularly well-run.

2. The government released the UK's 5G strategy in March 2017.
3. In 2017–2018 and 2018–2019, Ofcom intended to auction 150 MHz and 110 MHz channels in the 3.4–3.6 GHz band, respectively.
4. In order to organize 5G in a timely manner, Ofcom has unveiled a work platform on 26 GHz band accessibility.
5. The Italian government plans to auction the frequencies of 700 MHz, 3.6-3.8 GHz, and 26.5-27.4 GHz in 2018.
6. The 350 MHz of radio spectrum for 5G communications was successfully auctioned off by the Irish government.
7. In 2018, the Spanish government issued 3.6 GHz–3.8 GHz spectrum permits in response to operator and market requests.
8. Spain is emphasizing the 26 GHz frequency. In 2018, at least 1.4 GHz of bandwidth will be made accessible.

In the 2018–2019 time range, several nations including Austria, Belgium, and Switzerland are planning to liberate spectrum [6-7].

1.11 Antenna Basics

Radio-frequency (RF) energies are converted into electrical energies, or the other way around, via a specialized transducer known as an antenna. There are two basic types: the receiving antenna, which absorbs RF energy and delivers alternating current to the device, and the transmitting antenna, which receives electrical energy from the apparatus and creates radio-frequency field. The microstrip patch antenna, which is used for wireless communications, is the most common form of antenna used in wireless applications. Microstrip patch antennas are typically only suitable for use with microwave frequencies.

1.11.1 Frequency

Frequency, as used here, refers to how frequently an event occurs over a period of time. In its simplest form, frequency refers to the number of times an event occurs during a specific period of time. According to the standard definition, "Frequency" is defined as the quantity of times a signal occurs within a given time frame (one second). After 'T' seconds, also known as the time interval, the periodic signal repeats itself. The frequency of a periodic signal is just its inverse in terms of time (T). Frequency diagram is shown in figures 1.6 and 1.7. In engineering, the term "frequency" refers to the frequency of oscillatory and vibratory phenomena, including radio waves, audio transmissions (sound), mechanical vibrations, and light. German physicist Heinrich Hertz invented the hertz, the SI's (International System) unit of frequency (Hz). If a signal or event repeats once per second, it is said to be at one hertz.

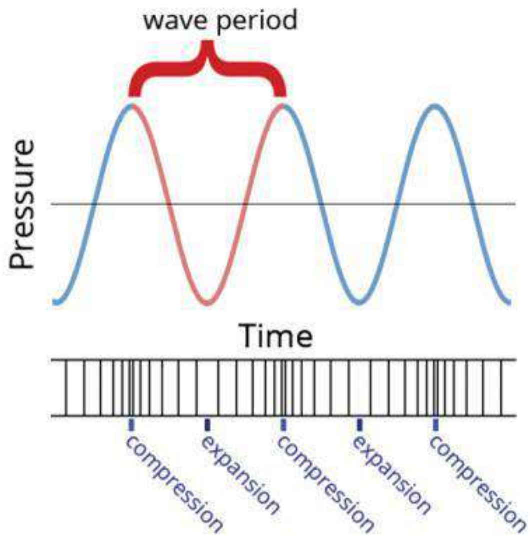


Figure 1.6. Frequency diagram

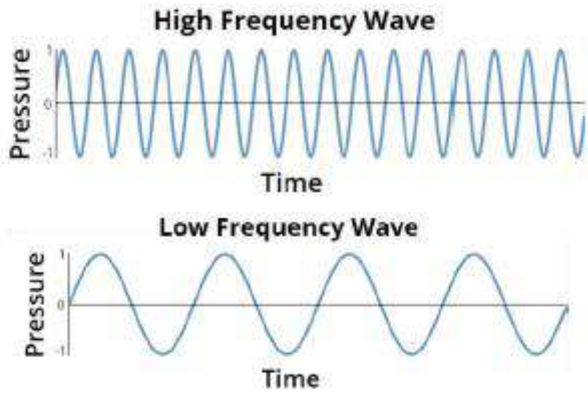


Figure 1.7. High frequency and Low frequency diagram

1.11.2 Bandwidth

The ability of a wired or wireless communications system link to send 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. The frequency range that an antenna can effectively emit or receive energy is referred to as its bandwidth. Frequently, one of the most important factors utilized to select an antenna is bandwidth. For instance, several antenna types cannot operate in wideband mode due to their extremely limited bandwidths. Diagram of bandwidth is shown in Figure 1.8.

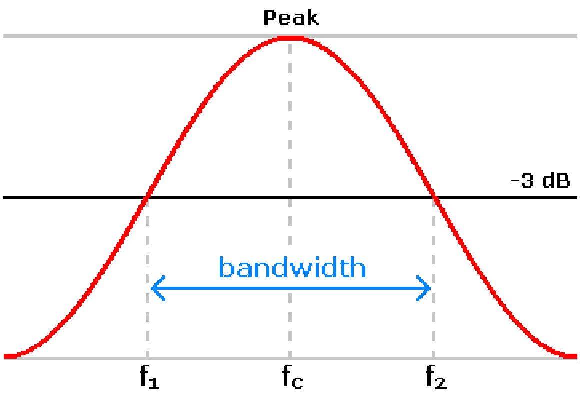


Figure 1.8. Bandwidth diagram

1.11.3 Input Impedance

The ratio of voltage to current at an antenna's input terminals is known as input impedance. It is a crucial antenna characteristic that expresses the antenna's resonance. The input impedance is divided into real and imaginary components. The actual component of the input impedance represents the power that is radiated away from or absorbed by the antenna. The imaginary portion of the input impedance known as reflected power serves as a representation of the power that is stored in the antenna's near field. An antenna that has zero imaginary impedance and actual input impedance is said to be resonant. The length and dimensions of an antenna affect its input impedance. Impedance is represented by the symbol Z, which contains a real part that includes the radiation resistance and ohmic losses of the antenna, Rrad and Rohmic, respectively [7].

1.11.4 Impedance Matching

The usual definition states that "Impedance matching" occurs when the approximate values of the impedances of a transmitter and receiver are equal or when they are opposite. Impedance matching is important for wireless communication between the circuitry and the antenna. Maximum power transfer theory states that maximum power transfer between an antenna and a receiver or transmitter happens when the antenna, transmission line, and electronics have suitable impedances. The process of impedance matching the antenna with the circuitry throughout a range of frequencies is referred to as tuning or matching the antenna. The bandwidth is the range of frequencies where the antenna impedance is close to 50 Ohms for a specific VSWR. VSWR is a measurement of the match's quality. Resonant describes a gadget that performs better at a certain, limited range of frequencies. Antennas are a type of resonant device whose output is enhanced by matching impedance.

The following is a list of requirements for impedance matching.

1. Power from the source will be efficiently delivered to the feed line if the impedance of the feed line and the source are the same.
2. The feed line's power will be effectively delivered to the antenna if the impedances of the feed line and antenna are compatible.
3. The output impedance of the antenna being utilized as the receiver should match the input impedance of the receiver amplifier circuit.
4. For a transmitter antenna, the input impedance of the antenna as well as the output impedance of the transmitter amplifier must all be compatible [9].

1.11.5 Directivity and Gain

Directivity refers to an antenna's capacity to emit energy in a certain direction when transmitting or to better receive energy coming from a specific direction when receiving. Additionally, gain is typically described as the difference between the power generated by an antenna from a far-field source on its beam axis and the power generated by an idealized lossless isotropic antenna that is equally sensitive to signals coming from all directions. The two concepts, gain and directivity, are related. When comparing a light bulb to a spotlight, the phenomenon of enhanced directivity helps to explain this relationship. In comparison to a 100-watt light bulb, a spotlight will produce more light in certain directions while producing less light in others. The light bulb is claimed to have less "directivity" than the spotlight. The spotlight is analogous to a high-directivity antenna. Gain is the directivity's useful value. Gain is mathematically equivalent to the product of directivity and efficiency. The efficiency of the antenna is a new parameter () that is included in the relationship between gain and directivity [8]. Gain and Directivity are shown in Figure 1.9.

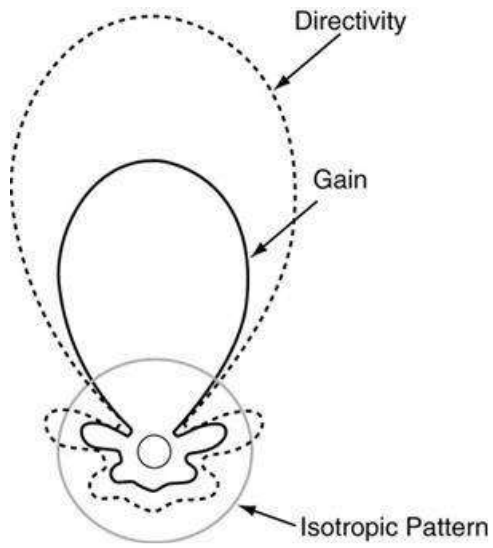


Figure 1.9: Directivity and Gain

1.11.6 Radiation Pattern

Radiation pattern, antenna pattern, and far field pattern are all terms used in the area of antenna design to describe the directional (angular) dependence of the intensity of the radio waves coming from the antenna. The relative intensity of the field that is emitted from the antenna at a certain distance is described by the radiation pattern. Since the radiation pattern also represents the antenna's receiving capabilities, it may also be referred to as the "reception pattern". Although the radiation pattern is three-dimensional, it is challenging to portray it in a way that is intelligible. Radiation pattern is seen in Figure 1.10. The measurement of a three-dimensional radiation pattern takes time as well. A two-dimensional radiation pattern that can be easily shown on a screen or sheet of paper is frequently the result of measuring a slice of a three-dimensional radiation pattern. The formats used to depict these pattern dimensions are rectangular or polar [7].

1.11.7 Voltage Standing Wave Ratio (VSWR)

The efficiency with which radio-frequency power is transported from a power source, through a transmission line, and into a load is gauged by the VSWR (Voltage Standing Wave Ratio). In other words, the standing wave ratio, which is a measurement of the ratio between the wave's greatest and minimum power (SWR). The voltage ratio of the incident voltage to the reflected voltage is known as VSWR.

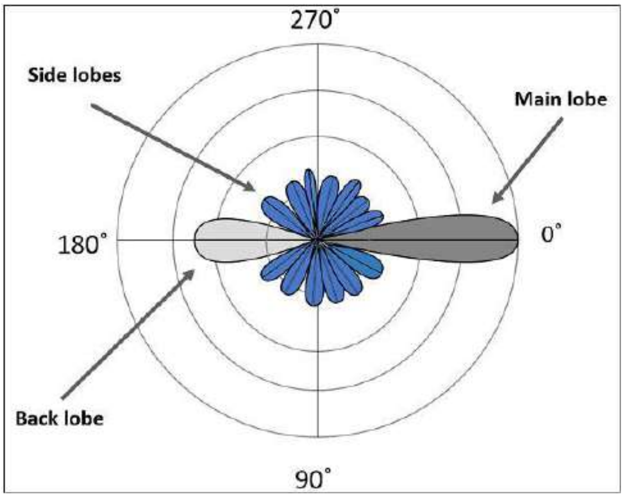


Figure 1.10. Radiation pattern

The VSWR for an antenna is always a precise and positive figure. More power is transmitted to the antenna and the antenna is better suited to the transmission line when the VSWR is reduced. VSWR must be at least 1. This is the optimal situation since no electricity is reflected from the antenna [7]. Figure 1.11 depicts the VSWR.

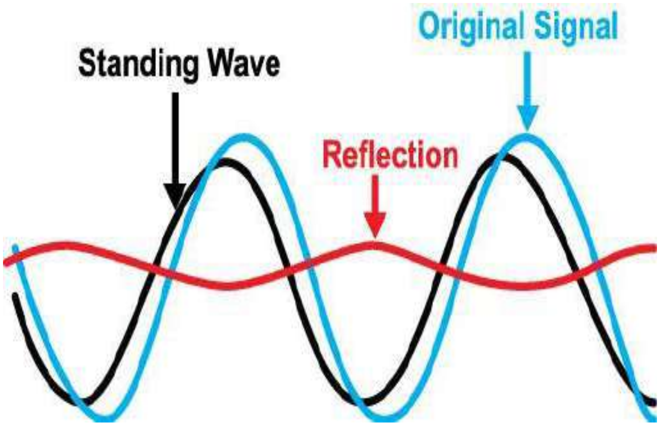


Figure 1.11. VSWR

1.11.8 Return Loss (RL)

The return loss of an antenna is a number that represents the percentage of radio waves that arrive at the antenna input that are rejected in comparison to those that are accepted. In relation to a short circuit, it is measured in decibels (dB) (100 percent rejection). Another term for the mismatch between the antenna and the feedline is return loss (RL). The algorithmic ratio compares the power reflected by the antenna to the power input into the antenna from the transmission line, and it is measured in dB. The RL and VSWR are intimately connected. In reality, S11 is the antenna parameter that is most frequently cited. S11 is only the return loss in reality (RL). Nothing is emitted and all powers are reflected from the antenna if S11 = 0 dB. If

S11 is equal to -6 dB, then the reflected power is equal to -3 dB if 3 dB of power is applied to the antenna. A RL or S11 of -9.5 dB or below corresponds to the allowable VSWR of less than or equal to 2. The RL of -10 dB is considered acceptable in this thesis [7].

1.11.9 Polarization

The electric field of the wave that the antenna emits determines the polarization of the antenna. The polarization of the antenna is specifically controlled by the strength and phase of the electric field. The antenna is linearly polarized if the components of the electric field have identical magnitudes and phases. The antenna is circularly polarized if the magnitudes are equal but the phases diverge by 90 degrees. The projected electric fields of two linearly polarized antennas must coincide for communication to occur. But regardless of its orientation, every linear antenna may communicate with a circularly polarized antenna. Each polarization type has a benefit; although a linear antenna radiates more power because all of the radiation is focused in one direction rather than being split among the two components, a circular antenna is orientation insensitive. The reader antenna can be either circular or linear depending on the application, and the tag antenna should preferably be circularly polarized so that it can be read from any orientation [8]. Three different polarization types are shown in Figure 1.12.

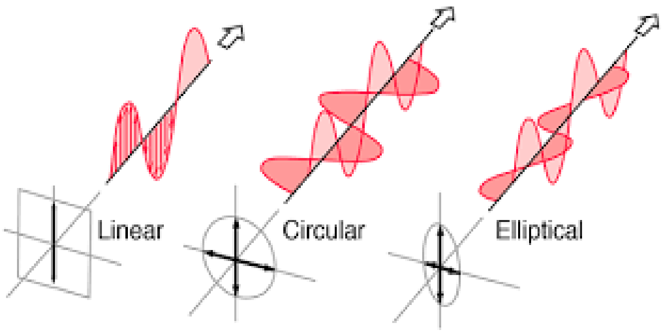


Figure 1.12 Polarization Linear, Circular, Elliptical [8].

1.12 Microstrip Antenna

As illustrated in Figure 1.13, a microstrip patch antenna comprises of a radiating patch on one side and a ground plane on the other of a dielectric substrate. The patch can have any form and is often constructed of conductive materials like copper or gold. Typically, the feed lines and radiating patch are photo etched onto the dielectric substrate. The patch is often square, rectangular, circular, triangular, or elliptical in shape to facilitate examination and performance prediction. The length (L) of a rectangular patch is typically 0.33330L 0.50, where 0 is the free-space wavelength. The patch is chosen to be extremely narrow so that t=0 (where tis the patch thickness). The dielectric substrate typically has a height of 0.003 h 0.05 0. The substrate's (r) dielectric constant normally falls between 2.2 and 12.

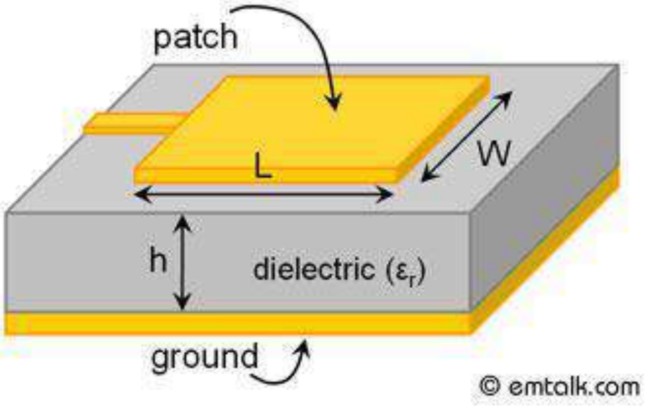


Figure 1.13 Structure of a Microstrip Patch Antenna [8].

The fringing fields between the patch edge and the ground plane are principally responsible for the radiation of microstrip patch antennas. A thick dielectric substrate with a low dielectric constant is preferred for optimal antenna performance because it offers higher efficiency, a wider bandwidth, and better radiation. However, this arrangement results in a higher antenna size. Higher dielectric constants, which are less effective and provide a narrower bandwidth, are required in the construction of tiny Microstrip patch antennas [8].

1.12.1 Microstrip antenna Feed Techniques

Different type microstrip antenna feed techniques are given below,

- Microstrip Line Feed
- Coaxial / Probe Feed
- Aperture Coupled Feed
- Proximity Coupled Feed

1.12.2 Microstrip Line Feeding

A microstrip transmission line is etched right up to the patch's border in this sort of feeding, keeping the entire structure in the same plane. In Figure 1.14, a microstrip feed line is shown.

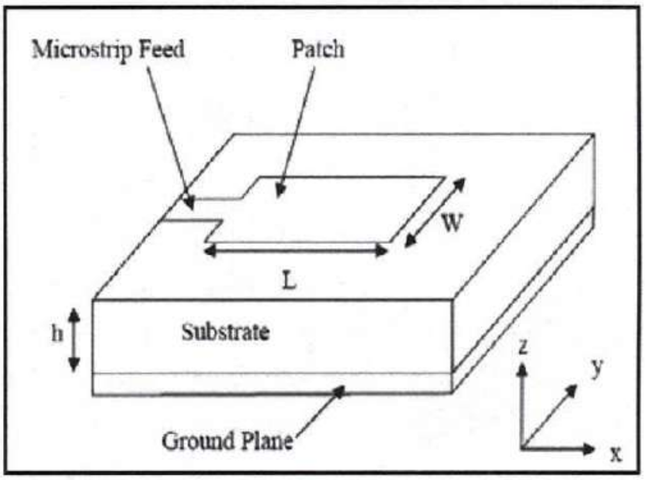


Figure 1.14 Microstrip Line Feeding [7].

1.12.3 Coaxial or Probe feeding

While the outer conductor of the coaxial connection is attached to the ground plane, the inner conductor is soldered to the radiating patch and passes through the substrate. In figure 1.15, coaxial feeding is displayed.

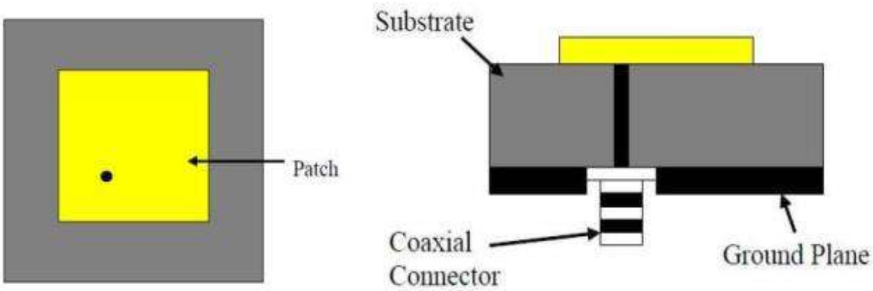


Figure 1.15 Coaxial / Probe feeding [7].

1.12.4 Aperture Coupled Feed

The aperture coupling in this kind of feed is made up of two substrates connected by a ground plane. The radiating patch and microstrip line, which are located at the base of the lower substrate, divide the ground plane. Through a ground plane slot or electrically tiny aperture, the connection is accomplished. Feed with an aperture is shown in Figure 1.16.

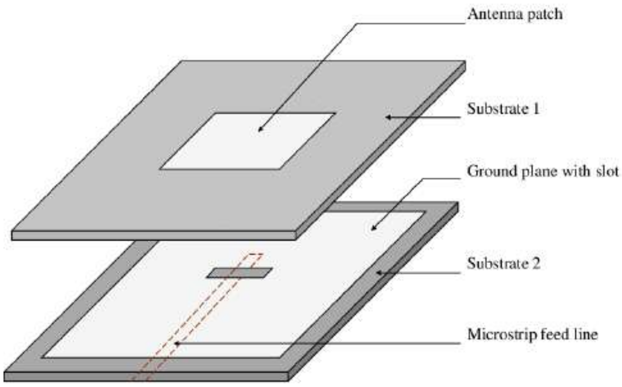


Figure 1.16 Aperture-Coupled Feed [7].

1.12.5 Proximity Coupled Feed

Electromagnetically Coupled ECMSA is another name for it. Additionally, it includes two substrates. The radiating patch is situated on the top of the upper substrate, and the microstrip feed line is situated between two substrates.

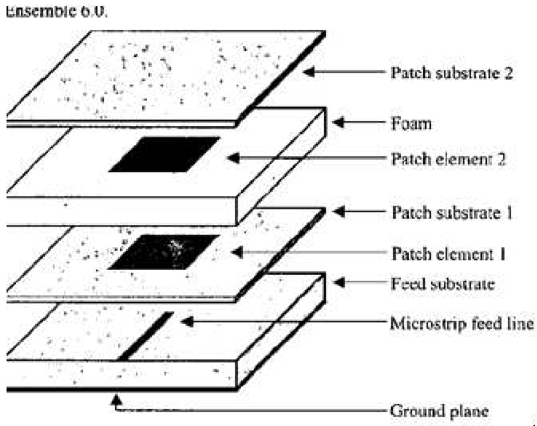


Figure 1.17 Proximity-Coupled Feed [7].

1.12.6 Advantages and Disadvantages of Microstrip Antenna

Microstrip patch antennas are becoming more and more common for usage in wireless applications due to its low-profile design, . As a result, they are quite compatible with embedded antennas in portable wireless devices like mobile phones and pagers. In order to be tiny and conformal, the telemetry and communication antennas on missiles are frequently microstrip patch antennas.

Below are a few benefits of the microstrip antenna:

- ✓ Microstrip antennas are compact and light-weight.
- ✓ They can be produced in huge quantities since they can be made inexpensively.

- ✓ They may readily be made conformal to the host surface due to their low profile planar design.
- ✓ Supports both circular and linear polarization
- ✓ Microstrip antennas and microwave integrated circuits may be readily integrated (MICs).
- ✓ They may operate on two and three frequencies.
- ✓ When installed on hard surfaces, they are mechanically durable.

Below are a few drawbacks of the micro-strip antenna:

- The bandwidth of a microstrip antenna is limited.
- Their productivity is poor.
- They have little gain.
- The feeds and connectors expose them to unnecessary radiation.
- The only tapered slot antennas are a poor end fire radiator.
- Their ability to handle power is limited.
- Excitation of surface waves

The antenna quality factor of microstrip patch antennas is quite high (Q). A big Q results in a limited bandwidth and poor efficiency since Q stands for the antenna's related losses. Q can be decreased by increasing the dielectric substrate's thickness. A surface wave absorbs an increasing portion of the source's overall power output. Since this surface wave contribution results in an unwelcome power loss is eventually dispersed at the dielectric bends and results in the loss of properties [8].

1.13 Design Tool

In these section properties about design tool is given.

1.13.1 CST Microwave Studio

A top-notch tool for the 3D electromagnetic modeling of high frequency buildings is CST MICROWAVE STUDIO (CST MWS). The user may quickly and accurately analyze high frequency components, such as antennas, filters, couplers, planar and multi-layer structures, as well as SI and EMC effects, using CST MWS. Both Time Domain and Frequency Domain solvers are present in the program. Design possibilities are improved and time is saved by filters for the import of particular CAD files and the extraction of SPICE parameters. For electromagnetic design and analysis, CST provides precise, effective computational solutions.

1.14 Motivation

From the beginning of wireless communication, it has become very popular due to cost of efficiency, flexibility, mobility & many more characteristics. In past few decades, the demand of data transmission rate, connection, features were growing vastly. Antenna became an integral part of wireless communication. At the very first of wireless communication era, generation wise antenna was developed. Currently a multipurpose antenna became more demanding as by using one device, it can be used for many applications. This demand actually gave us boost to develop the antenna which at a time can be used for multiple applications along with giving high performance.

1.15 Essence

The industry of telecommunication is evolving rapidly. A new generation emerges roughly every ten years. The previous one, 5G, is the one that researchers are most interested in. With the massive advancements in wireless technology, we have gone from Fourth Generation (4G) to Fifth Generation (5G). After 4G/IMT-Advanced, 5G is the next generation of wireless communication protocols. The Internet of Things, huge machine connectivity, and device to device ultra reliability are all aided by the development of 5G, which is coming with higher capabilities than current 4G and will provide a better density for wireless network users (IoT). We need to create antennas that are compatible with 5G technology since wireless communication is impossible without the use of an antenna.

Because of its unmatched qualities, the microstrip patch antenna is the most used antenna in modern wireless communication. This antenna type will produce smaller end devices because of its reduced size. Any PCB may simply have the microstrip-based antennas etched on it. The microstrip patches are simple to etch and come in a variety of forms, including rectangular, square, and triangular ones. They can be mass produced because of their cheaper manufacturing costs. They can accommodate many frequency bands (dual, triple). They support both linear and circular dual polarization. They weigh very little. Sub-6-GHz bands are used by the present 4G network for communication. However, the 5G needs cannot be supported by the available spectrum resources in these bands [10]. As a result, we must go to the higher frequency bands, which range from 6 to 300 GHz. As a result, the 3.4-3.6 GHz, 5-6 GHz, 24.25-27.5 GHz, 37-40.5 GHz, and 66-76 GHz bands are all suitable for 5G wireless communications [9], and the federal communication commission has designated 27.5-28.35 GHz for 5G [10]. The construction of high gain microstrip patch antennas for 5G communication at 28 GHz [2] and 38 GHz has been the subject of several studies. However, according to the FCC, some of those antennas do not fully cover the 28 GHz and 38 GHz bands, while others are too wide to be used with 5G mobile phones. Therefore, it is crucial to create an antenna that would work with 5G smart phones and span the 28 GHz and 38 GHz spectrum.

Chapter 2
Literature Review

2.1 Paper Review

The investigation into the fifth generation (5G) mobile application using the current antenna will be effective if the works of other researchers that are connected to this thesis, "Design and Simulation of a High Gain Microstrip Patch Antenna for 5G Wireless Communications," are reviewed in this part. As a result, an antenna with superior performance and simple manufacturing should be designed and simulated.

1. Research paper on**, "Simple Geometry Multi-Bands Antenna For Millimeter-Wave Applications At 28 GHz, 38 GHz, And 55 GHz Allocated To 5G Systems."**
   A compact umbrella shape antenna has been designed which is able to perform at tri-band frequency. This antenna is featured with both 5G mm-Wave & V-band application. [11]

2. Research paper on**, "Compact High Gain Micro-strip Patch Multi-Band Antenna for Future Generation Portable Devices Communication."**
   A compact multi-band antenna with micro-strip line feed is designed to operate at multiple frequencies with high performance for future generation wireless device to develop the communication system. Main task was to make their antenna capable of integrating into mobile & space constraint appliance. [12]

3. Research paper on**, "Design of A Dual-Band Microstrip Antenna for 5G Communication**."
   A Micro-strip Four Element Array Antenna is designed which supports dual band. The antenna is featured with 5G higher band & mm wave application. [13]

4. Research paper on**, "Compact Dual-Band Antenna with High Gain and Simple Geometry for 5G Cellular Communication Operating at 28 GHz and 44 GHz."**
   A dual-band circular patch antenna is designed which gave high performance for multiple higher frequency which can be worked in mobile & satellite communication system which contains the context of 5th Generation technology. [14]

5. Research paper on, **"A low Profile Multiband Microstrip Patch Antenna For 5G mm-Wave Application**."
   A multiband microstrip patch antenna, which is low profile, is designed. It is suitable for 5G mm-Wave wireless application as it performs at multiple high frequencies. [15]

6. Research paper on, **"Compact Square patch antenna for 5G Communication."**
   A compact microstrip antenna (MSA) is designed to communicate signals in the sub 6GHz band of 5G communication, particularly 3.4 -3.6GHz band. [16]

7. Research paper on, **"High Gain Compact Multi-Band Microstrip Patch Antenna for 5G Network**."
   A novel high gain compact multi-band microstrip patch antenna is designed for the unlicensed millimeter-wave (30 GHz to 300 GHz) band applications for 5G. Main motive behind this paper is to design a high gain multi band compact size microstrip patch antenna for 5G mobile communication. [17]

8. Research paper on, **"Multiband Microstrip Patch Antenna for 5G Wireless Communications."**
   A dual band U-shaped slotted Microstrip patch antenna with 28GHz and 38GHz operating bands is designed. The proposed antenna can be used as communicating tool and analyzed for one band and dual band communication at higher frequencies (mm-waves) for 5^{th} generation network. [18]

9. Research paper on, **"A Compact, T-Slotted Wide Band Microstrip Antenna with Defected Ground Structure for Future 5G Communications."**
   A compact T slotted wide-band micro-strip patch Antenna with defected ground square structure is designed. The proposed antenna can exhibit Omni-directional radiation pattern at higher multiple frequency, which is required for 5G applications. [19]

10. Research paper on, **"A Novel Dual-Band (38/60 GHz) Patch Antenna for 5G Mobile Handsets."**
    A novel dual band (38/60 GHz) micro-strip patch antenna is designed for 5G mobile handsets to combine complicated radiation mechanisms for dual-band operation. A low

profile antenna can operate in higher frequency bands like 38 GHz & 60 GHz and saves power by combining two bands in a single compact antenna. [20]

11. Research paper on, **"Design of Multi-segmented Dual Band Microstrip Patch Antenna for 5G Application."**
    A multi-segmented dual-band rectangular monopole antenna with partial ground is designed for 5th generation based communication. Researchers mainly investigate the effect of different substrate materials and thickness on design performance by designing a multi-segmented dual band micro-strip patch antenna operating at 28GHz and 37GHz respectively. [21]

12. Research paper on, **"Shared-Surface Dual-Band Antenna for 5G Applications."**
    A shared-surface dual-band antenna is proposed for 5G operation using characteristic mode analysis (CMA). The surface is the integration of a Meta surface at S-band and a partially reflective surface (PRS) at Ka-band. [22]

13. Research paper on, **"S-Shaped Slotted Multiband High Frequency UWB Antenna for 5G Applications."**
    They actually did it in two parts. At first, they examined single band antenna that works within the range of frequency bandwidth from 27.67GHz to 28.33GHz. Then they examined dual band antenna which is operated from 27.02GHz to 27.52GHz and 36.14GHz to 36.71GHz respectively. To get result in dual band, they cut S shape slot in single band antenna. Here, they actually use Rogers RT 5880 as substrate materials, which dielectric constant of 2.2. The width, length and height of the designed antennas are 7.7 mm, 7.9 mm and 0.254 mm respectively. They actually tried to keep their antenna. [23]

14. Research paper on, **"Design miniaturized Compact High Gain Micro-strip Patch Multi-Band Antenna for Future Generation Portable Devices Communication."**
    They actually tried to build multi-band micro-strip patch antenna. To get high gain for multiple frequencies, they cut the I shape slot in both side of antenna. Here, they use the substrate Rogers RT-5880. The antenna dimensions 21 × 16 × 0.507 mm3 with dielectric value 2.2 and 0.0009 tangent loss. [24]

15. Research paper on**, "Compact Dual-Band Antenna with High Gain and Simple Geometry for 5G Cellular Communication Operating at 28 GHz and 44 GHz."**

Their proposed antenna was dual band antenna. To get performance in multiple frequencies, they used two circular patches along with elliptical shape patch. To improve performance of antenna, they cut orthogonal elliptical slot from the antenna. Here, they use RT Duroid 5880 material as substrate & the dimensions are 15 mm X 15 mm X 0.79 mm**.** [25]

16. Research paper on**, "Design of A Dual-Band Micro-strip Antenna for 5G Communication."**

They tried to create Micro-strip Four Element Array Antenna which supports dual band. The operating frequencies are 29 GHz &38 GHz. They select these frequencies to make it contender for 5G wireless communication technologies. As they worked on dual band four elements array antenna, they used RT Duroid 5880 as substrate. It has a thickness of 1.575 mm. The dimensions are 20 mm X 25 mm. [26]

17. Research paper on, **"Multiband Microstrip Patch Antenna Operating at Five Distinct 5G mm-Wave Bands."**

They actually designed a novel mm-Wave multiband microstrip patch antenna for 5G wireless communication. To get high performance at multiple higher frequency, they designed their antenna H-shaped with inset feed and a rectangular slit in the upper side of the radiating patch. The dimensions of their designed antenna 7.5 mm X 8.5 mm X 0.55 mm. [27]

18. Research paper on**, "A low Profile Multiband Microstrip Patch Antenna For 5G Mm- Wave Wireless Applications."**

They have designed multiband microstrip patch antenna that is low profile & suitable for 5G mm-Wave wireless application as it performs at multiple high frequencies. They have done it so that their antenna is compact enough to incorporate into various 5G mm-Wave application. They have done it by following below process –

- ✓ They take dimensions 8.6 mm X 9.2 mm X 0.6 mm.
- ✓ They make it as rectangular shape structure.
- ✓ Slotted inset feed line
- ✓ They try to keep it lightweight, low cost & small size. [28]

.

19. Research paper on**, "A Compact Tri-Band Antenna for 28 GHz, 38 GHz, and 55 GHz band Applications**."

    They have done compact tri-band umbrella shape antenna for future mm-Wave application. They have done it so that their antenna is compact enough to incorporate into various 5G mm-Wave application & V band application. They have done it by following below process –

    - ✓ They take dimensions 8 mm X 9 mm X 0.79 mm.
    - ✓ Take RT Duroid – 5870 as substrate.
    - ✓ Make the shape of antenna like an umbrella.
    - ✓ They are try to keep it multiband operational, compact size & geometrical structure. [29]

20. Research paper on, **"Compact Square patch antenna for 5G Communication."**

    They have designed a compact microstrip antenna (MSA) to communicate signals in the sub 6GHz band of 5G communication, particularly 3.4 -3.6GHz band. They have done it so that their antenna is capable enough to use for cellular 5th generation mobile communication. They have done it by following below process –

    - ✓ It is fed by coaxial feeding.
    - ✓ Take RT Duroid as substrate.
    - ✓ Square slot is etched from the patch.
    - ✓ Increased the thickness of substrate. [30]

21. Research paper on**, "High Gain Compact Multi-Band Microstrip Patch Antenna for 5G Network."**

    They have designed a novel high gain compact multi-band microstrip patch antenna for the unlicensed millimeter-wave (30 GHz to 300 GHz) band applications for 5G. They have done it so that they can achieved a high gain multi band compact size microstrip patch antenna for 5G mobile communication. They have done 5 types of design by taking 5 types of material as substrate which are FR-4 (loss free), FR-4 (lossy), RT-5880, RT-3003, RT-6010. The dimensions are 12.9 mm X 11.29 mm X 1.2 mm. [31]

22. Research paper on**, "Multiband Microstrip Patch Antenna for 5G Wireless Communications."**

    A dual band U-shaped slotted Microstrip patch antenna with 28GHz and 38GHz operating bands is presented in this paper. They have done it so that their proposed antenna can be used as communicating tool and analyzed for one band and dual band communication at higher frequencies (mm-waves) for 5th generation network. They have done it by following below process –

- ✓ The total area of their proposed antenna is 8.5 mm X 8 mm X .254 mm.
- ✓ They etched U shape slot from the patch.
- ✓ They use Rogers RT-5880 as substrate. [32]

23. Research paper on, **"A Compact, T-Slotted Wide Band Microstrip Antenna with Defected Ground Structure for Future5G Communications."**

They have done a compact T slotted wide-band micro-strip patch Antenna with defected ground square structure for 5G communication. They have done it so that the antenna can exhibits Omni- directional radiation pattern at higher multiple frequency which is required for 5G applications. They have done it by following below process –

- ✓ The size of ground plane of their proposed antenna is $0.308\lambda o \times 0.308\lambda o \times 0.009\lambda o$ with design centre frequency 22 GHz.
- ✓ They etched T shape slot from the patch.
- ✓ They have introduced rectangular notch in the antenna.
- ✓ They take Rogers RT-5880 as substrate. [33]

24. Research paper on**, "A Novel Dual-Band (38/60 GHz) Patch Antenna for 5G Mobile Handsets."**

They have designed a novel dual band (38/60 GHz) micro-strip patch antenna for 5G mobile handsets to combine complicated radiation mechanisms for dual-band operation. They have done it so that they can offer a low profile antenna which can operate in higher frequency bands like 38 GHz & 60 GHz. They want to save power by combining two bands in a single compact antenna. They have done it by following below process –The antenna is composed of two electromagnetically coupled patches. Rogers RO3003TM is used as substrate material. [34]

25. Research paper on**, "Design of Multi-segmented Dual Band Microstrip Patch Antenna for 5G Application."**

They have tried to design A multi-segmented dual-band rectangular monopole antenna with partial ground for 5th generation based communication. They have done this to investigate the effect of different substrate materials and thickness on design performance by designing a multi-segmented dual band micro-strip patch antenna operating at 28GHz and 37GHz respectively. They have done it by following below process –

- ✓ The antenna consists of single patch having ground size of 17.5 X 5.83 mm.
- ✓ Rogers RT Duroid-5880 is used as substrate material.
- ✓ The substrate thickness is .45 mm.
- ✓ Placed three slots at edges of the patch to improve the impedance matching and fed by 50 Ω microstrip line. [35]

2.2 Summary

Designing microstrip patch antennas for millimeter wave and V bands, such as 28 GHz, 38 GHz, and 56 GHz, has been the subject of several studies. According to the most recent studies, the millimeter wave bands of 28 and 38 GHz and the V band of 50 to 75 GHz range are the most promising and significant candidates for 5G wireless communication. This is because several studies have been conducted that cover these frequency ranges. Again, designing antennas with high gain to overcome severe path-loss, sufficient miniaturizes to be able to integrate in mobile phones, efficient and easy to manufacture as well, is the most difficult task in 5G deployment.

2.3 Objectives

- ❖ To design a Tri-band Microstrip Patch Antenna for 5G mmWave and V-band applications.
- ❖ To achieve better gain, efficiency, and a low coefficient of reflection.
- ❖ Preserve the smallest feasible antenna size.

Chapter 3

Methodology

3.1 Methodology

The systematic, theoretical evaluation of the procedures used in a field of research is known as methodology. It comprises a theoretical investigation of the collection of practices and beliefs connected to a field of knowledge. It often includes ideas like standards, theoretical models, stages, and quantitative or qualitative research procedures [37]. A set of activities or processes is referred to as methodology. The methodologies utilized in a specific research project, as well as practices that are often applied across a field of study or business may be referred to by this name. A methodology, on the other hand, does not aim to provide solutions; as a result, it is not the same as a method. A methodology, on the other hand, deals with the theoretical support for comprehending which approach or combination of procedures may be realistic to a certain instance.

3.2 Research Design

Research design is characterized as the framework created to address the research questions. A research project's design identifies the research tools, including the study topic, dependent and independent variables, experimental design, and, if necessary, data collecting techniques and a strategy for statistical analysis.

The research's methodology was as follows:

- → Study on evolution towards 5G.
- → Study on antenna requirements for 5G.
- → Select 5G millimeter wave band.
- → Select 5G V-band
- → Study literature on microstrip antenna and existing 5G antennas.
- → Study procedure of microstrip antenna design.
- → Study antenna design procedure in CST Microwave Studio.
- → Calculate necessary parameters to design antenna.
- → Find out best substrate material.
- → Find out best substrate height.
- → Find out best feeding technique.
- → Implement the procedure.

3.3 Pilot Study

Prior to carrying out a full-scale research project, a pilot study, pilot project, pilot test, or pilot experiment is carried out as a small-scale introduction study to evaluate feasibility, time, cost, hostile occurrences, and enhance the study design. It is carried out before the anticipated study. Typically, pilot studies are carried out according to the study's original plans. Although a pilot study cannot completely rule out systemic mistakes or unanticipated issues, it significantly reduces the number of errors that cause time and effort to be wasted during the primary research study.

Pilot study importance:

- ❖ To evaluate the research methodology or technique.
- ❖ To classify problematic variables and decide how to functionalize each one.
- ❖ To create or evaluate the performance of research tools and methodologies
- ❖ To assess statistical variables for future research.

3.4 Software

Technology for Computer Simulations A potent tool for the 3D electromagnetic modeling of high frequency components is called Microwave Studio (CST MWS). High frequency (HF) devices such filters, couplers, antennas, single and multi-layer structures, as well as SI and EMC effects, may be quickly and precisely analysed using CST MWS.

CST MWS is the top option in industry-leading research and development departments because of its unmatched performance. CST MWS, which is incredibly user-friendly, instantly provides the user with a glimpse into the EM behavior of high frequency designs [38].

3.5 Design procedure

- ❖ **Step 1:** Firstly, tri-band rectangular microstrip patch antenna (MPA) is designed to operate in mm-Wave band & V-band, based on the basic equations of designing MPA which is called equation-based antenna.
- ❖ **Step 2:** Secondly, suitable substrate material is used to find out best one based on 5G requirement.
- ❖ **Step 4:** Now using different feeding techniques to find best one based on 5G requirement.
- ❖ **Step 5:** best substrate material, best substrate height and best feeding technique used to design the antenna.
- ❖ **Step 6:** Save the structure and simulate the developed antenna.
- ❖ **Step 7:** Save the result if antenna meet criteria.
- ❖ **Step 8:** Optimize the developed Microstrip patch antenna for better performance.
- ❖ **Step 9:** Save the result if antenna meet criteria.
- ❖ **Step 10:** Compare the result with existing antennas.

- **Step 11:** Writing the report
- Flow Diagram of the Research work shown in figure 3.1.

3.5.1 Antenna Substrates

The choice of a suitable dielectric substrate with the required thickness is the initial stage in antenna design (h). To increase electrical and mechanical stability, dielectrics are utilized. They aid to create displacement current, which in turn produces a magnetic field that varies over time in accordance with Ampere's Law, and they are used to lower the size of the antenna. By using Faraday's law, this time-varying magnetic field may generate an electric field that is also time-varying, resulting in the creation of a propagating electromagnetic field. In this method, a substrate can improve the antenna's capacity for radiation.

The parameters of a few popular dielectric substrates are provided in table 3.1.

TABLE 3.1: LIST OF SUBSTRATES

Dielectric Name	**Dielectric constant**
FR4	4.4
RT Duroid-6002	2.94
RO4730	3
Rogers RO 3200	3.02
Rogers RT Duroid-5880	2.2
Rogers RT Duroid-5870	2.33
Foam	1
TLC-32	4.3

The substrates in the table above have relatively high dielectric constants, which indicate substantial loss when building high gain antenna. First, we choose at random a substrate material, Rogers RT-5880, whose dielectric constant is near to 2.2 and which is frequently used for MPA design. Then, the microstrip line and ground material should be chosen. We have three options in this situation: copper, silver, or gold. Compared to the others, silver has a higher conductivity. But compared to the other two, copper is both significantly harder and more affordable. Thus, copper is typically utilized.

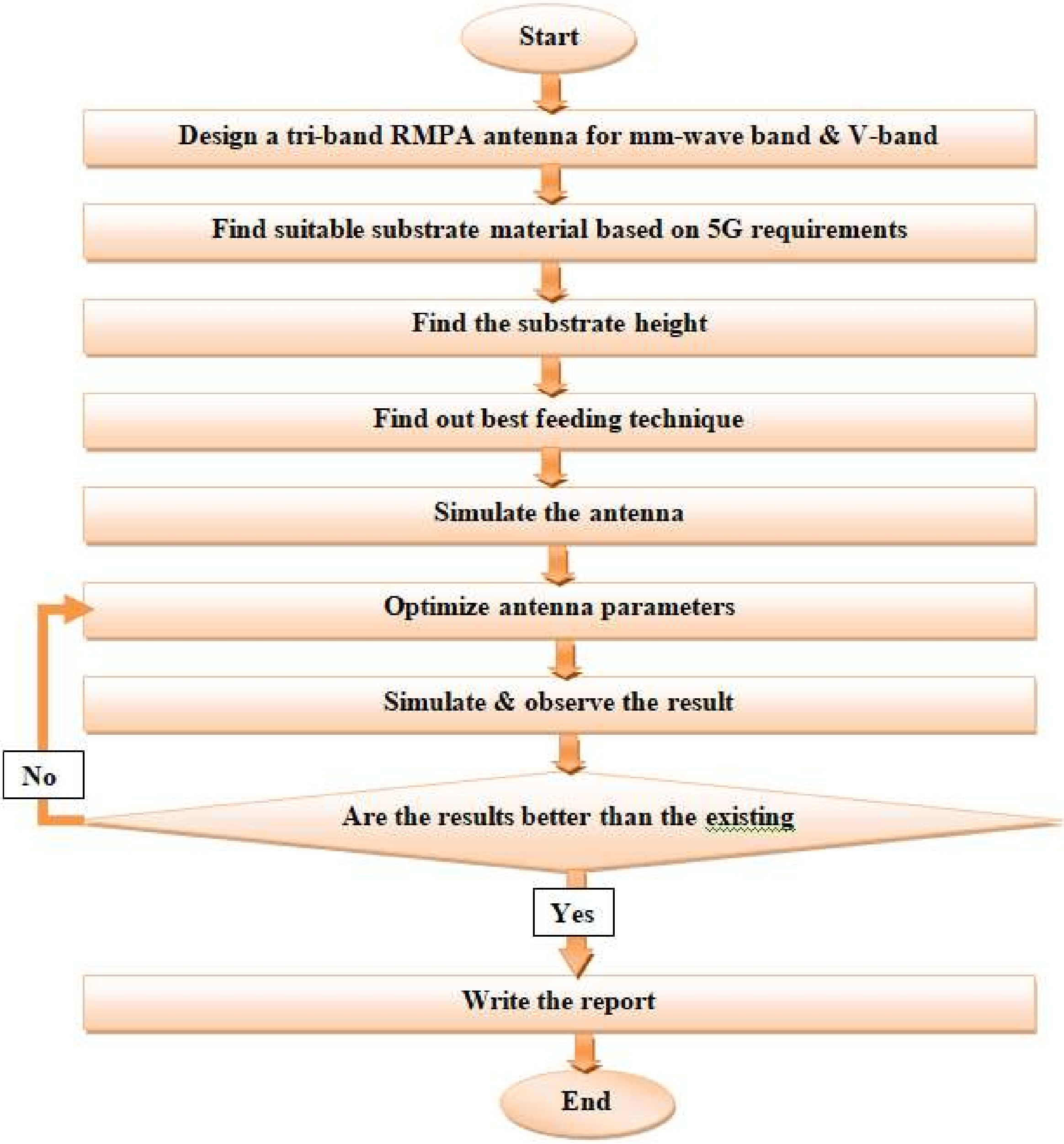


Figure 3.1 Flow Diagram of the Research work

3.5.2 Antenna Design by Equation

There are various sections in this aspect of the process for antenna design. The first step in creating the antenna radiating patch is determining the patch's length and breadth, which is the main focus of this episode. The dielectric constant of the substrate (r), height of the substrate (Hs), and resonance frequency of the antenna are the sub-parameters needed to construct this antenna radiating patch [39]. The feeding method has also been developed. This antenna is designed using two different feeding methods, the first of which is inset fed and the second of which is the quarter wave transformer feeding method. Finally, the feeding method for the quarter wave transformer has been chosen.

The fundamental equations (1-11) [40] & [41] for designing a microstrip patch antenna that will help to get better results are given below.

3.5.2.1 Calculating Substrate Height

Substrate height can be calculated by formula shown in Eq. 1 -

Substrate Height. $Hs \approx \frac{.0606\,\lambda}{\sqrt{\epsilon r}}$ ……………………..………………………..…....(1)

Where,

Wavelength, $\lambda \approx \frac{c}{fr}$……………………………………………………….…..(2)

Here,

C = Velocity of light = $3 \times 10^{8} \mathrm{ms}^{-1}$

fr = Resonant frequency.

$\in r$ = Substrate dielectric constant

3.5.2.2 Calculating Patch width

We required to calculate patch width given in Eq. 3 -

Patch Width, $Wp = \frac{c}{2fr}\sqrt{\frac{2}{\epsilon r+1}}$……………………………………………………..(3)

3.5.2.3 Calculating Patch length,

Patch Length, $Lp = L_{\mathrm{eff}} - 2\Delta L$……………………………………..................... (4)

The effective length, L_{eff} & its deviation, ΔL is calculated by using the equation,

$$L_{\mathrm{eff}} \approx \frac{c}{2\,fr\sqrt{\frac{\epsilon r+1}{2}+\frac{\epsilon r-1}{2}\left[1+\frac{12Hs}{Wp}\right]^{\left(-\frac{1}{2}\right)}}}$$ ………………...(5)

$$\Delta L \approx 0.412\left(\frac{\epsilon eff+0.3}{\epsilon eff-0.258}\right)\left(\frac{\frac{Wp}{Hs}+0.264}{\frac{Wp}{Hs}+0.8}\right)$$ …………………………………………..….(6)

3.5.2.4 Calculating Ground Width

$WG = 6Hs + Wp$………………………………………………………….…....…(7)

3.5.2.5 Calculating Ground Length,

$LG = 6Hs + Lp$……………………………..…………………………..……….(8)

3.5.2.6 Calculating feed depth & notch gap,

Feed depth, $Xo \approx \frac{.822 \times Lp}{2}$……………………………..……………………..…....(9)

Notch Gap $\approx \frac{C}{\sqrt{2\epsilon eff}} \times \frac{4.65 \times 10^{-2}}{fr}$………………………..(10)

3.5.2.7 Calculating the width of 50Ω feed lines,

$$Wf \approx \frac{120\,\pi}{\epsilon eff\,(1.393 + \frac{Wp}{Hs} + \frac{2}{3}\ln(\frac{Wp}{Hs} + 1.444))}$$ ………..……(11)

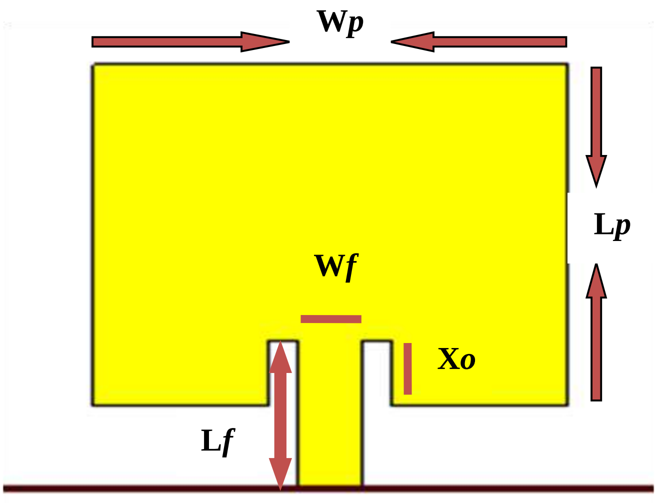


Figure 3.2. Equation based primary designed antenna

TABLE 3.2: Primary design antenna parameter

Parameter	Value (mm)
Substrate Height, Hs	.485
Dielectric Constant, $\in r$	2.2
Patch Width, Wp	5

Patch Length, Lp	5
Substrate Width = Ground Width	7.5
Substrate Length = Ground Length	7
Feedline Width, Wf	.745
Feedline Length, Lf	1
Gap Space, Wc	.3

3.5.3 Cutting Slot

After designing primary microstrip patch antenna based on equation, then our target was to make our antenna tri-band. To obtain tri-band capability, we have to cut slot. By cutting slot, we not only improve our gain & efficiency but also reduce return loss. The parameters to cut slot are given below –

Width 1, W1 = .10 mm & Length 1, L1 = 3.30 mm

Width 2, W2 = .10 mm & Length 2, L2 = 1.59 mm

Width 3, W3 = .10 mm & Length 3, L3 = 0.80 mm

View from CST Studio suit of designed microstrip patch antenna with cutting slot for tri-band is shown below –

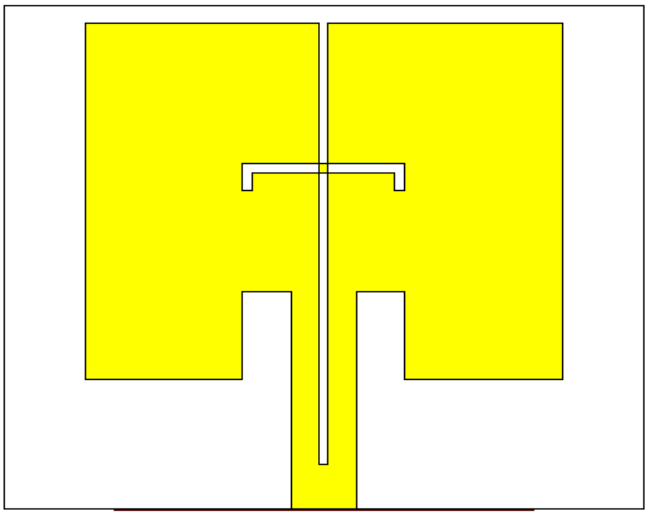


Figure 3.3. Front view of antenna after cutting slot

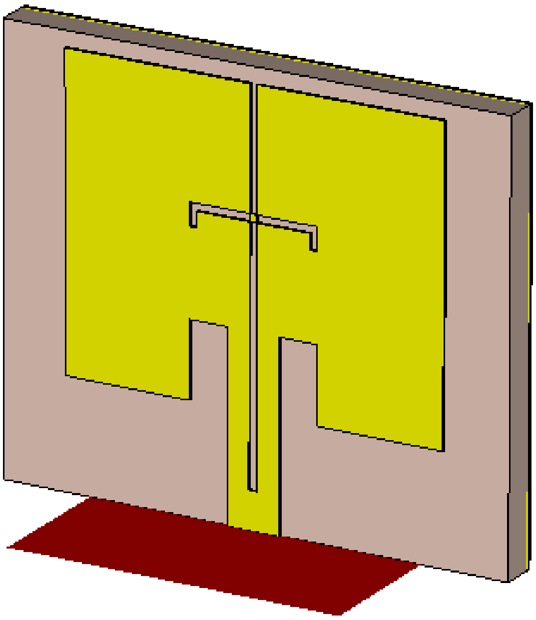


Figure 3.4. Side view of antenna after cutting slot

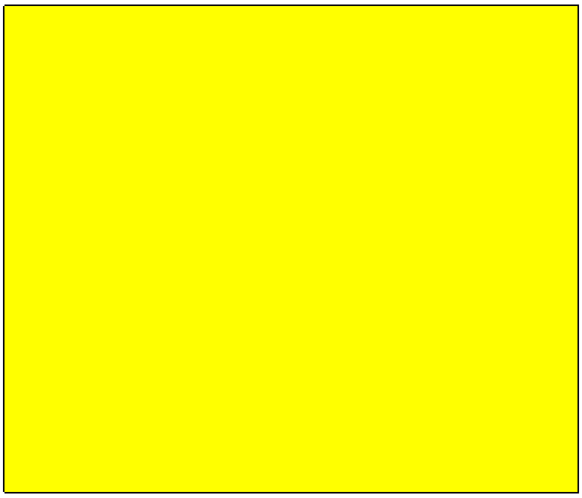


Figure 3.5. Ground view of antenna

3.5.4 Optimization through optimizer in CST Studio Suit

The designed antenna is optimized through optimizer in order to get more accurate result & to make the antenna more efficient. By keeping in mind some specific parameters, the designed antenna is optimized & has found the following optimized parameters to proceed the design antenna to be efficient.

TABLE 3.3: Optimized parameter of designed tri-band patch antenna

Parameter	**Value (mm)**
Substrate Height, Hs	.499
Dielectric Constant, $\in r$	2.2
Patch Width, Wp	5.02
Patch Length, Lp	4.03
Substrate Width = Ground Width	6.7140604925791
Substrate Length = Ground Length	5.6912443240875
Feedline Width, Wf	0.675000014159336
Feedline Length, Lf	2.9173607278005
Gap Space, Wc	0.515

Chapter 4

Result Analysis

The findings acquired after simulating the constructed antenna are provided & analyzed in this section.

4.1 Results of Designed Tri-Band Microstrip Patch Antenna (Primary Design)

4.1.1 Return Loss Graph

The return loss or S 11 parameter is the most essential part to examine the efficiency of antenna. Return loss delivers data on an antenna's reflected energy. It is easy to find out the operating frequency & the antenna bandwidth from the return loss vs frequency graph. The return loss vs frequency graph is given in figure 4.1. From the graph, the operating frequencies are 36.72 GHz, 41.91 GHz & 49.98 GHz & the return losses are 42.12 dB, 22.54 dB & 35.37 dB respectively.

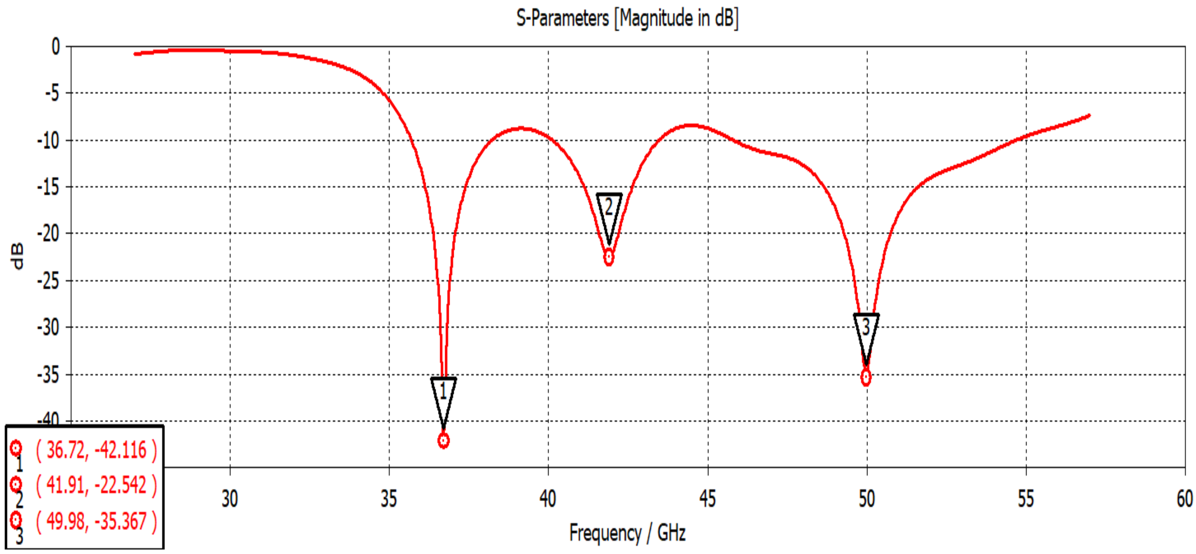


Figure 4.1. Return loss plot of primary designed patch antenna

4.1.2 Voltage Standing Wave Ratio (VSWR)

The capability of matching the impedance of an antenna with its radio or transmission line is known as voltage standing wave ratio (VSWR) [42]. In the case of 5G, the VSWR value should stay between 1-2. Gradually low value for VSWR will define the better matching of impedance with a transmission line of antenna. In figure 4.2, the VSWR's are 1.0158, 1.1613 & 1.0347 for primary tri-band antenna for operating frequency at 36.72 GHz, 41.91 GHz & 49.98 GHz respectively. We know that the ideal value of VSWR is 1 which means no power is reflected from the antenna.

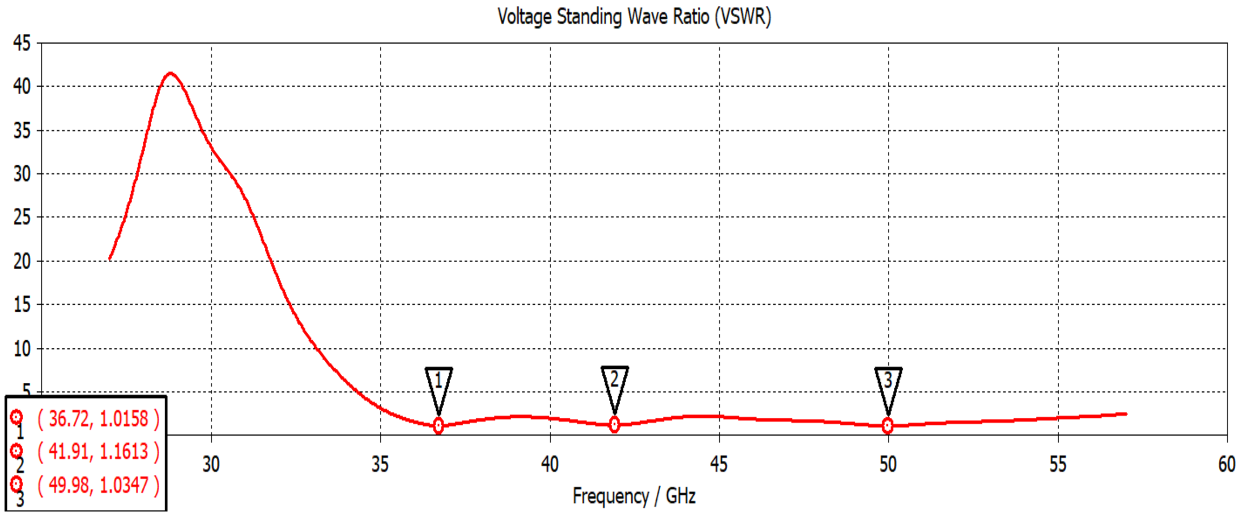


Figure 4.2. VSWR of primary designed patch antenna

4.1.3 Efficiency

The ratio of delivering power to the antenna & radiated power from the antenna is known as efficiency. In the case of 5G communication, the ideal efficiency rate is above 70 %. In the proposed antenna without optimization, efficiencies are 91.116 %, 87.78 %, and 78.91 % at operating frequencies 36.72 GHz, 41.91 GHz & 49.98 GHz respectively. Figure 4.3 shows the efficiencies of the primary designed patch antenna.

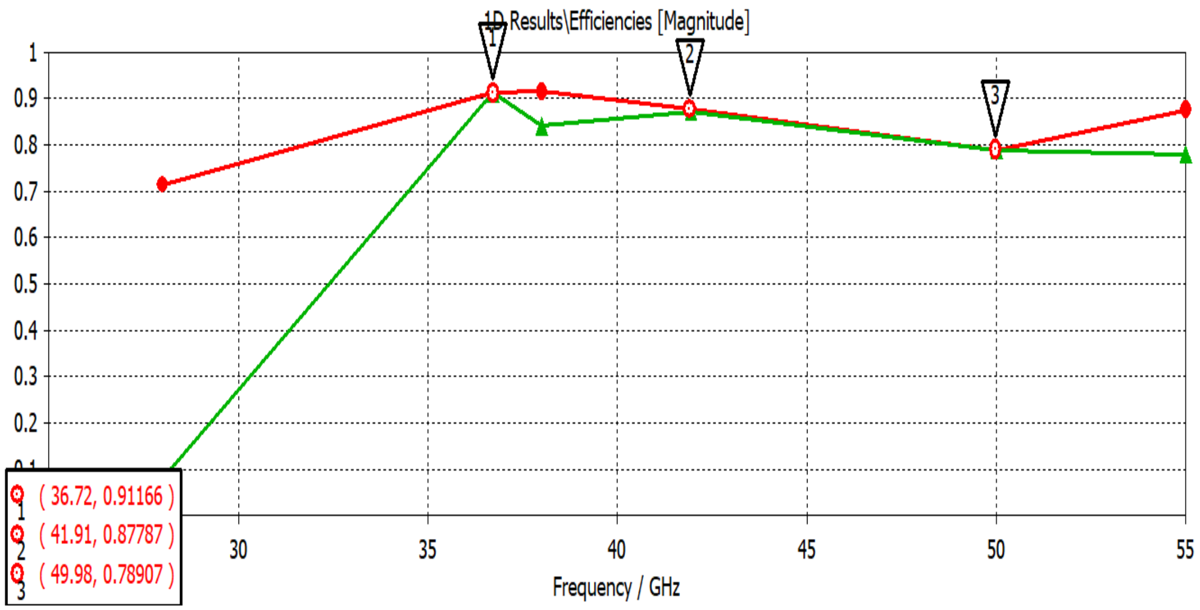
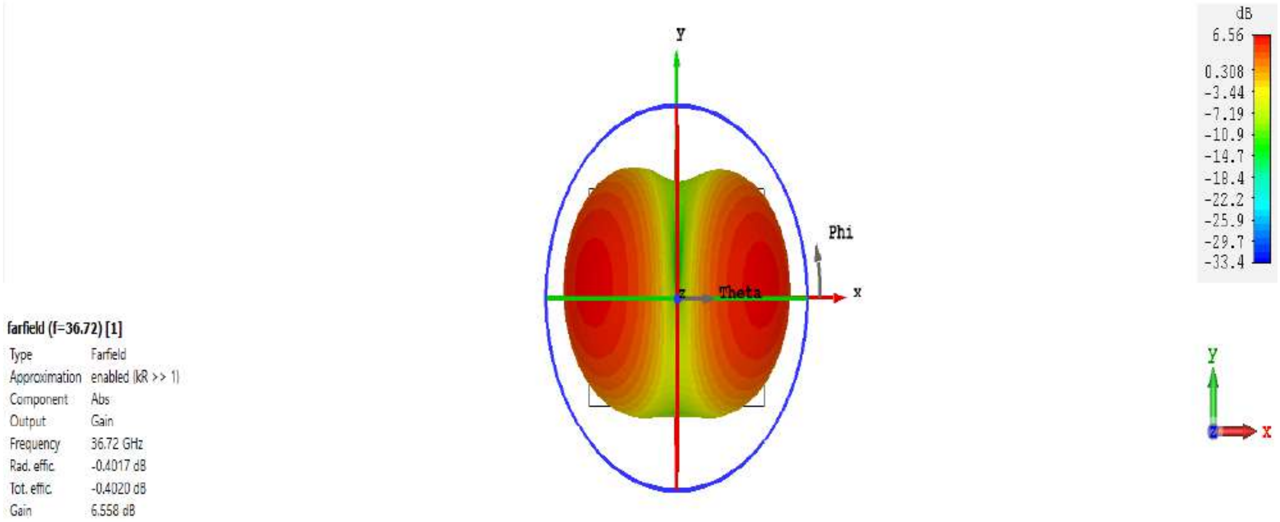


Figure 4.3. Efficiencies of primary designed patch antenna

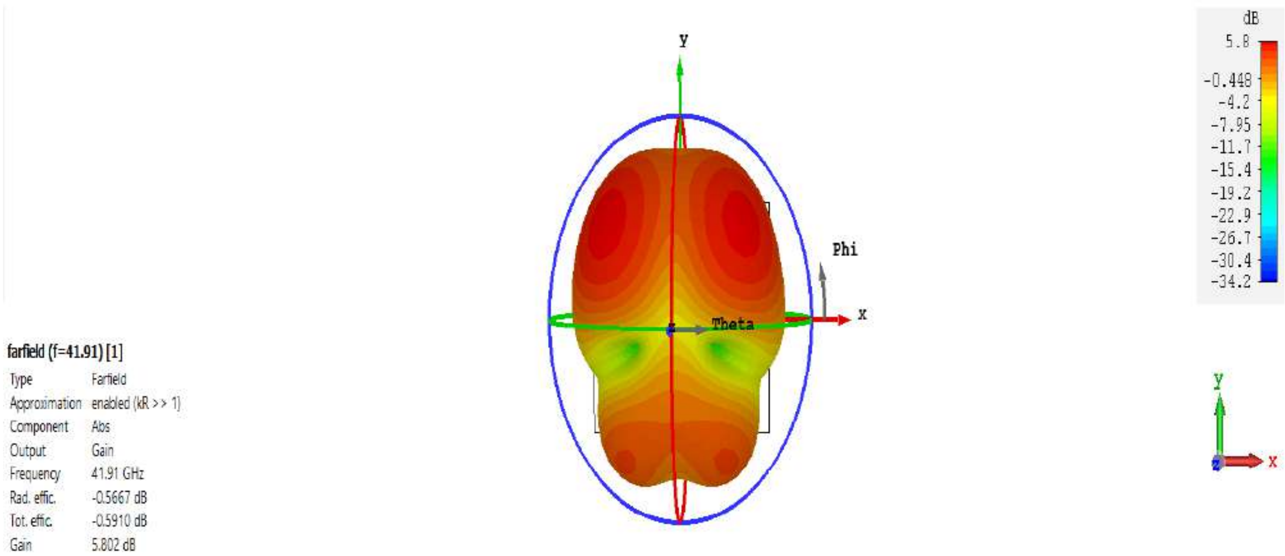
4.1.4 3D Radiation Pattern

A 3D radiation pattern is a three dimensional perspective of how energy in the surrounding room is radiated by an antenna. Generally, this pattern is measured at an adequate distance from the far-field known antenna. Simply put, it is the energy that radiates in some direction with regard to an isotropic antenna.

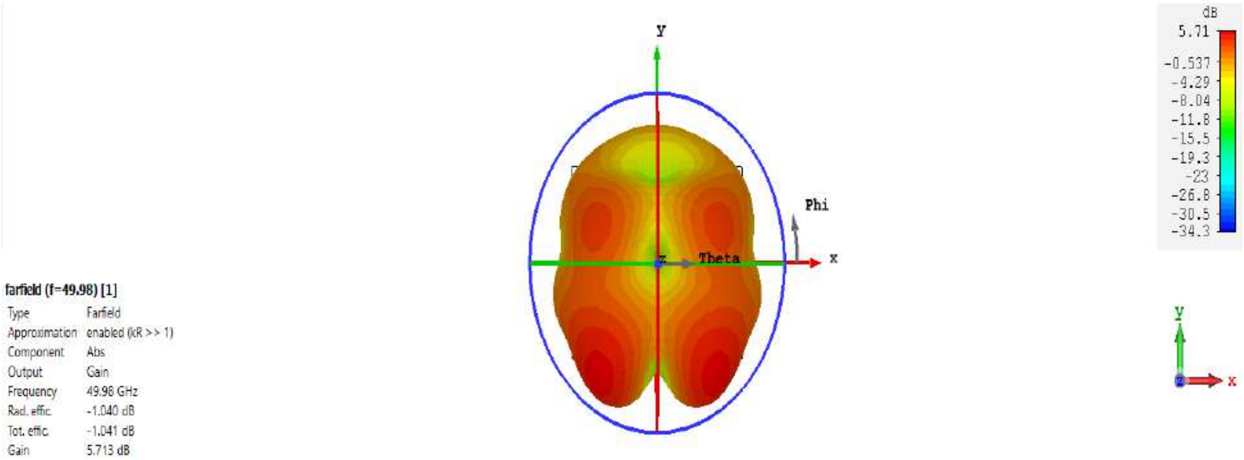
3D Radiation pattern of proposed primary designed antenna at three operating frequencies of 36.72 GHz, 41.91 GHz & 49.98 GHz are shown in Figure 4.4 (a), (b) and (c), respectively. It is clearly observed from figure that, at 36.72 GHz, the gain is 6.558 dB. Similarly, for 41.91 GHz, the gain is 5.802 dB & lastly, the gain for operating frequency 49.98 GHz is 5.713 dB.



(a) 36.72 GHz



(b) 41.91 GHz



(c) 49.98 GHz

Figure 4.4. 3D radiation pattern of primary design antenna

4.2 Result of Primary Designed Tri-band Microstrip Patch Antenna

TABLE 4.1: Total simulation result of primary designed tri-band microstrip patch antenna

Parameters	Value	Standard [43]
Size (mm^2)	5.00 x 5.00	As per need
Resonant Frequencies (GHz)	36.72, 41.91, 49.98	As per need
S 11(dB)	-42.12 dB, -22.54 dB, -35.37 dB	Less than -10 dB
VSWR	1.0158, 1.1613, 1.0347	1>==<2
Efficiencies (%)	91.116 %, 87.78 %, 78.91 %	Above 70%
Directivity (dBi)	6.959, 6.368, 6.752	5 – 8 dBi
Gain (dB)	6.558, 5.802, 5.713	5 – 8 dB

4.3 Results of Designed Tri-Band Microstrip Patch Antenna (After optimization)

At first, we get genuine result without any optimization. Then, we optimized by considering some selective parameters & then we get upgraded result at every section.

4.3.1 Return Loss Graph

The return loss vs frequency graph is given in figure 4.5. From the graph, the operating frequencies are 36.72 GHz, 41.73 GHz & 49.89 GHz & the return losses are 43.794 dB, 23.84 dB & 34.125 dB respectively. Optimized antenna is more efficient than primary designed antenna as return loss of two operating frequencies are improved.

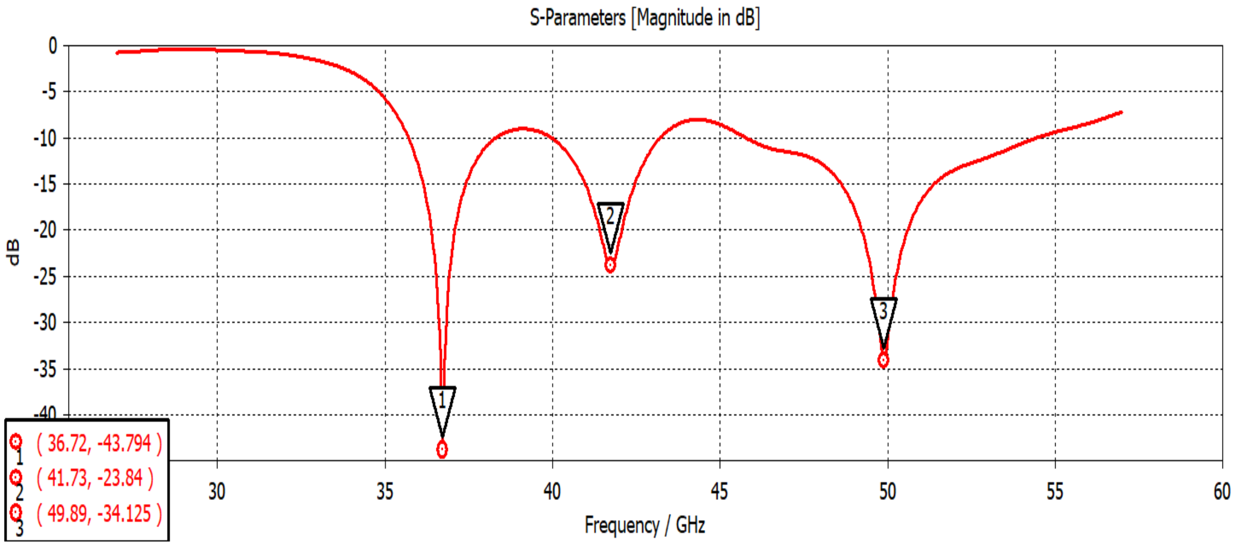


Figure 4.5. Return loss plot of optimized tri-band patch antenna

4.3.2 Voltage Standing Wave Ratio (VSWR)

In figure 4.6, the VSWR's are 1.013, 1.1374 & 1.0401 for optimized tri-band antenna for operating frequency at 36.72 GHz, 41.73 GHz & 49.89 GHz respectively. We know that the ideal value of VSWR is 1 which means no power is reflected from the antenna. After optimization VSWR improves a little bit than the previous primary design of patch antenna.

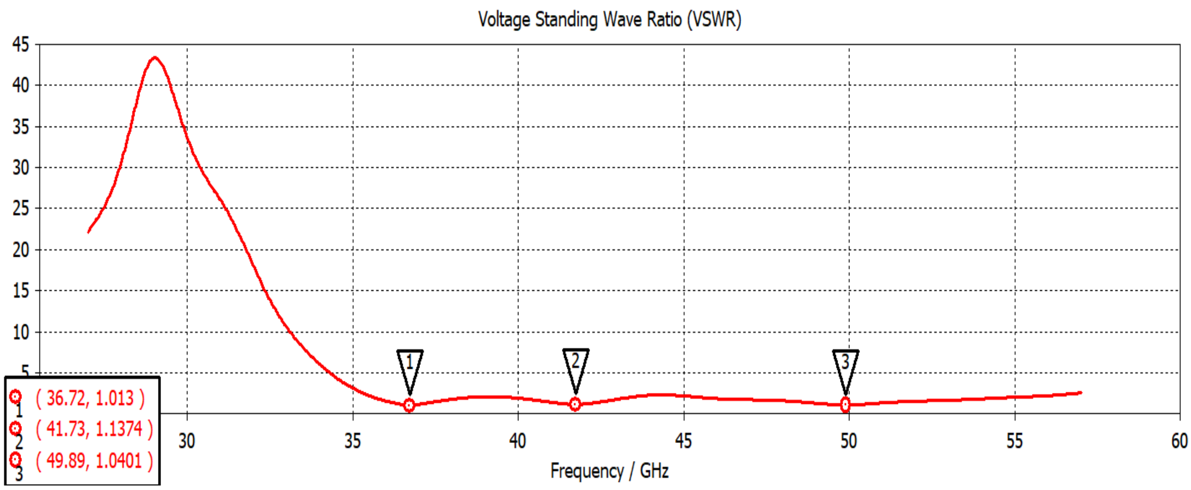


Figure 4.6. VSWR of optimized tri-band patch antenna

4.3.3 Efficiency

In the optimized tri-band patch antenna, efficiencies are 91.186 %, 88.012 %, and 78.48 % at operating frequencies 36.72 GHz, 41.73 GHz & 49.89 GHz respectively. Figure 4.3 shows the efficiencies of the primary designed patch antenna. Efficiencies are improved slightly after optimization.

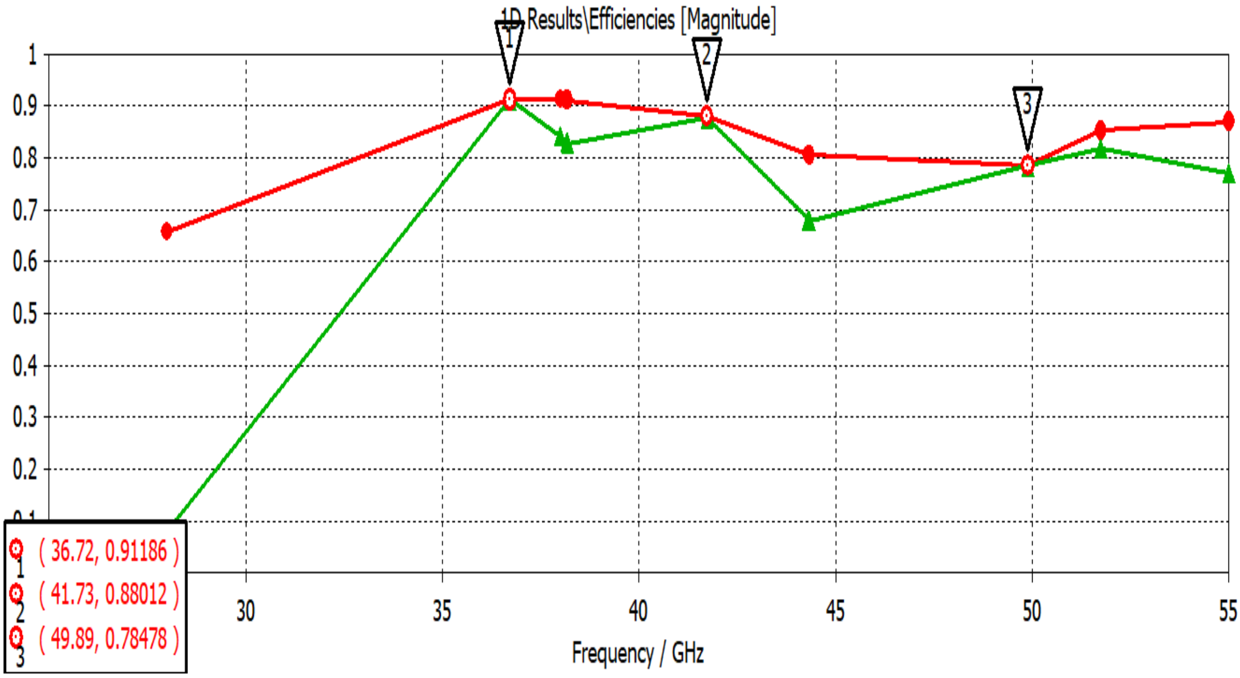
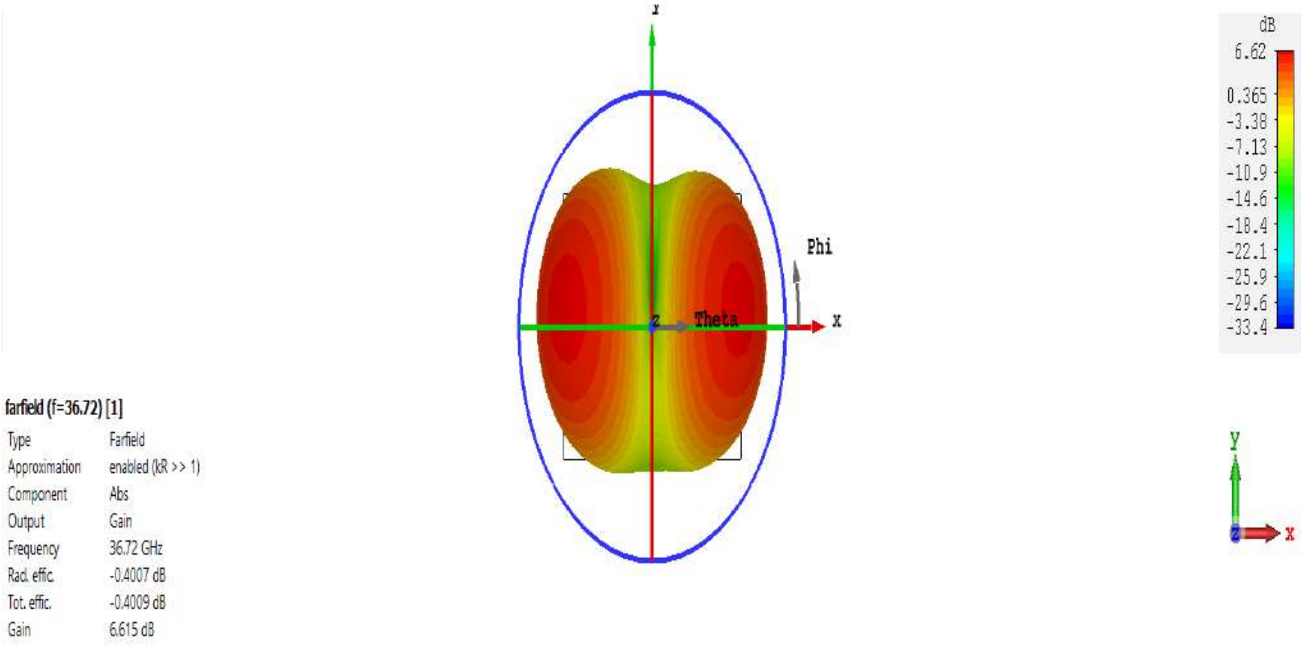


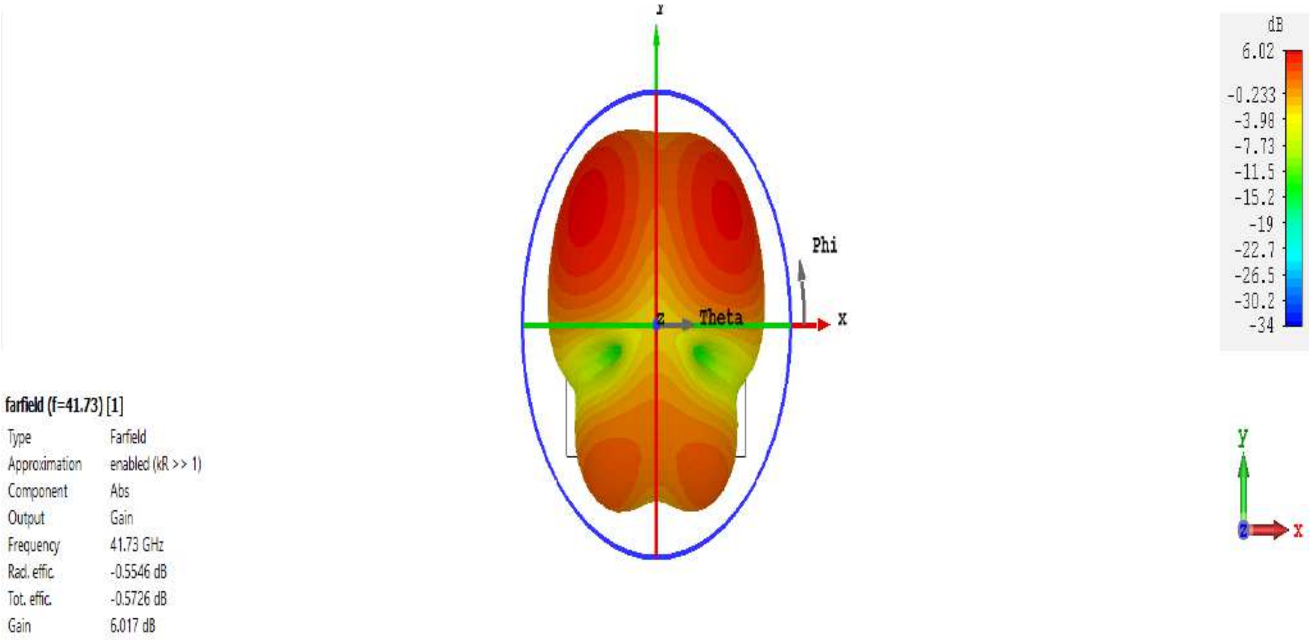
Figure 4.7. Efficiencies of optimized tri-band patch antenna

4.3.4 3D Radiation Pattern

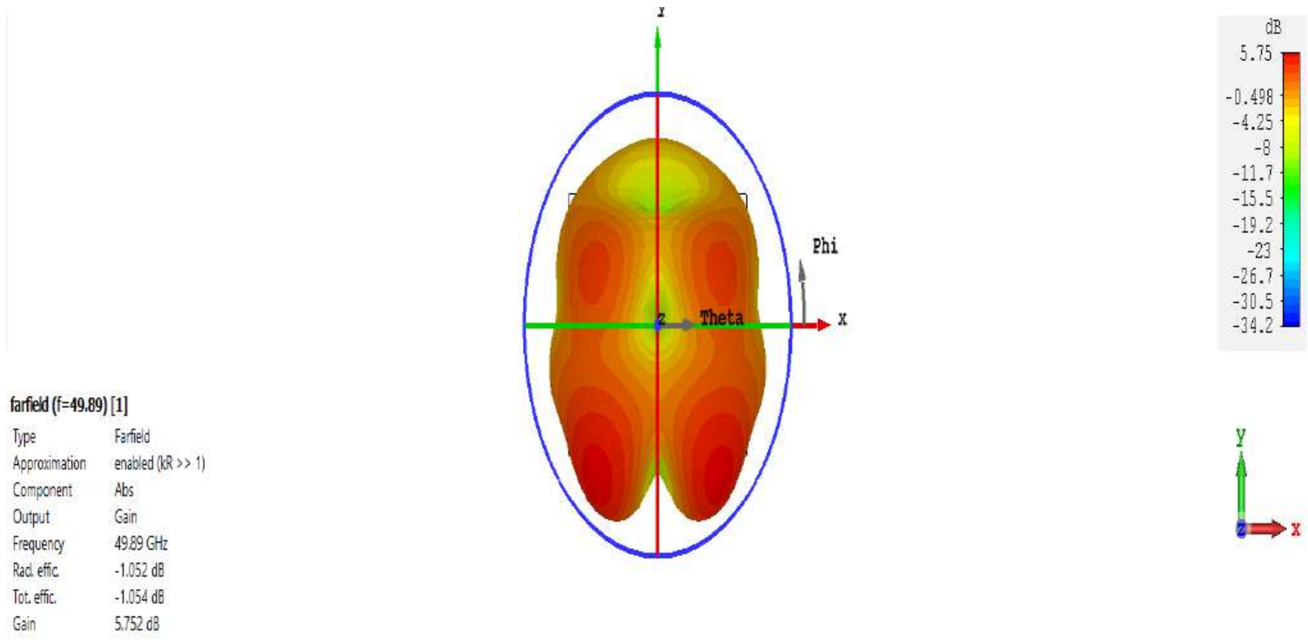
3D Radiation pattern of the optimized tri-band patch antenna, three operating frequencies 36.72 GHz, 41.91 GHz & 49.98 GHz are shown in Figure 4.8 (a), (b) and (c), respectively. It is clearly observed from figure 4.8 that, at 36.72 GHz, the gain is 6.615 dB. Similarly, for 41.73 GHz, the gain is 6.017 dB & lastly, the gain for operating frequency 49.89 GHz is 5.752 dB.



(a) 36.72 GHz



(b) 41.73 GHz



(c) 49.89 GHz

Figure 4.8. 3D radiation pattern of optimized tri-band patch antenna

4.4 Final Result of Designed Tri-band Microstrip Patch Antenna

TABLE 4.2: Total simulation result of optimize tri-band microstrip patch antenna

Parameters	Value	Standard [43]
Size (mm^2)	5.02 x 4.03	As per need
Resonant Frequencies (GHz)	36.72, 41.73, 49.89	As per need
S 11(dB)	-43.794 dB, -23.84 dB, -34.125 dB	Less than -10 dB
VSWR	1.013, 1.1374, 1.0401	1>==<2
Efficiencies (%)	91.186 %, 88.012 %, 78.48 %	Above 70%
Directivity (dBi)	7.016, 6.572, 6.805	5 – 8 dBi
Gain (dB)	6.615, 6.017, 5.752	5 – 8 dB

4.5 Comparison with the existing tri-band antennas

In the table 4.3, our proposed antenna's performance are compared with recent designed tri-band antennas by researchers.

TABLE 4.3: Comparison the proposed antenna with existing antennas

Antenna Ref	Year	Resonate Frequency (GHz)	Return Loss (dB)	Gain (dB)	Efficiency (%)
[44]	2018	24.4, 28, 38	14.7, 19.3, 18.7	6.65, 7.02, 6.46	85.37, 86.5, 73.3
[45]	2019	29, 37.7, 41	25, 21, 11	9.49, 11.8, 7.69	-
[46]	2018	10.15	20	4.4	-
[47]	2019	28, 38	45, 40	6,6	93, 91
[48]	2019	10.4, 27.5, 37.8	13, 23.5, 10.5	5.67, 9.33, 9.57	-
[29]	2021	28, 38, 55	-	6.8, 7.3, 7.75	82, 85, 79
Proposed	2022	36.72, 41.73, 49.89	43.794, 23.84, 34.125	6.615, 6.017, 5.752	91.186, 88.012, 78.48

Chapter 5
Conclusion

The results of this study show that a high gain, tri-band Microstip patch antenna (MPA) designed with CST Microwave Studio is meant to operate on the three bands of 36.72 GHz, 41.73 GHz, and 49.89 GHz. We carved a slit near the feed-line and achieved an effective outcome to enable the suggested antenna's tri-band functionality. We first receive the outcome without any optimization. Our outcome was admirably good, yet it fell short of expectations. In order to achieve high performance from the antenna, which was sufficient, we improved the specified antenna. Without any impediment, we received our three bands. Our return loss for the three bands was extremely low, and the antenna's efficiency was great, ensuring the antenna's good performance. Our antenna was optimized to meet 5G specifications.

5.1 Achievements

In this thesis work, high gain tri-band microstrip patch antenna is designed and simulated successfully with 50Ω probe feed. The size of the proposed antenna is 5.02 mm x 4.03 mm & thickness .499 mm. It can easily be integrated into devices with space constraints. The antenna structure is built on low loss Rogers RT5880 substrate of 2.2 relative permittivity. The proposed antenna operates at 36.72 GHz, 41.73 GHz, and 49.89 GHz bands with return loss below -10dB. To reduce interference between the 5G systems and other systems in band, '+' shape slot is etched near feed-line to reject unwanted frequency bands. The VSWR of the simulated antenna is less than 1 through the whole frequency band which maintains the standard to exist between 1 and 2. Antennas gains are 6.615, 6.017 and 5.752 for 36.72 GHz, 41.73 GHz, and 49.89 GHz respectively. The efficiencies are 91.186 %, 88.012 %, 78.48 % for 36.72 GHz, 41.73 GHz & 49.89 GHz respectively which is better than the existing antennas found in literature review in terms of size. So, the proposed antenna is a strong candidate to be used in future 5G mobile phones.

5.2 Limitations

The suggested antenna lacks beam directing capabilities, which will make it more useful for u sage in mobile phones. Its bandwidth also needed to be improved.

5.3 Future Work Field

The mm-wave band has proposed a new generation of wide-area cellular networks to support massive IoT applications of the future. However, it will require significant changes at multiple layers of the protocol stack to reach this lofty goal. Consumers today demand ever faster wireless. Although wireless engineers have multiple tricks up their sleeves to meet this demand, they can achieve only so much. To deliver the gigs customers crave, more spectrums are required.

The power of 5G wireless depends on the use of millimeter wave (mmWave) bands to deliver larger gigabit capacities. Some 5G deployments will be in the sub-6 GHz band, specifically the 3.65 GHz band in the United States with a total of 150 MHz of available spectrum, but the broadband industry is shifting its attention to frequencies of 24 GHz and more. These higher-frequency mmWave bands have GHz of spectrum available to generate gigabit connectivity and accommodate 5G services. Initial focus has been on 24, 28 and 39 GHz, but because of the enormous number of internet of things (IoT) devices and new broadband services for homes and business connected via 5G networks, various industry players also are looking at the rich potential of bands far above that. The FCC recently held auctions for 28 GHz and 24 GHz, with more auctions for 37, 39 and 47 GHz planned for the future. These higher-frequency mmWave bands hold great promise for delivering 5G, gigabit per second services.

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