BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATIONS ENGINEERING

Design and Simulation of a Multiband Patch Antenna for 5G Wireless Communication

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Dedication

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

Certificate of Approval

The thesis titled "**Design and Simulation of a Multiband Patch Antenna for 5G Wireless Communication"** Submitted by **Mohin Uddin** bearing **Matric ID: T153002**; **Nuriad Islam** bearing **Matric ID: T153003**; of Academic Year: February 2021, Session: Autumn 2020 has been found as satisfactory and accepted as partial fulfillment of the requirement for the B.Sc. in Electronics and Telecommunications Engineering on International Islamic University Chittagong

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

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In the name of Allah, the Most Merciful, the Most Merciful. All praise and glory is 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 (pbuh) who guides and inspires our lives. We express our sincere gratitude and indebtedness to our thesis supervisor **Muhammad Mostafa Amir Faisal**, for his initiative in this field of research, valuable guidance, encouragement throughout the time of research. We express our thankfulness to **Engr. Syed Zahidur Rashid**, Chairman of the Department of Electronic and Telecommunications Engineering, IIUC for providing us with best facilities in the department and his timely suggestions. We are also thankful to **Muhammad Mostafa Amir Faisal**, Convener of our thesis for his dedication and sacrifice. We also express our sincere gratitude to all of our teachers for their best efforts throughout our academic years. And so far, we remember our parents for their support in our lives. And we also express our gratitude to our friends, well-wishers, for their direct or indirect involvement in the completion of this thesis.

Abstract

This paper presents a dual-band Microstrip Patch Antenna (MPA) using slot to be used in 4G and 5G systems. Because of broader bandwidth, slot patch antennas are very useful in commercial applications like 4G and 5G. Therefore, the main motive of this research work is to design slot antenna for 4G and 5G wireless communication. This work also can be provided for many devices such as Wi-Fi, WLAN (Wireless LAN) etc in future. And, it can also be used for lots of bands. This antenna is designed and simulated with CST Microwave Studio and operates on a band of 2.6 GHz and 28 GHz. Rogers RT-5880 material is used as a substrate which is 2.2 relative permittivity. The gain, bandwidth, return loss, VSWR and efficiency of the designed antenna at 2.6 GHz are 6.422 dBi, 85.8 MHz, -23 dB, 1.14, 70% and for 28 GHz 8.621 dBi, 3231MHz, -16 dB, 1.35, 90% respectively.

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List of Symbols

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

List of Abbreviations

RT	Duroid 5880
IEEE	Institute of Electrical and Electronic Engineers
LTE	Long Term Evolution
5G	Fifth Generation
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
FCC	Federal Communication Commission
SDR	Software Define Ratios
GSM	Global System for Mobile communication
3D	Three Dimension
2D	Two Dimension
VSWR	Voltage Standing Wave Ratio
WCC	Wireless Communication Centre
IE3D	Moment of Method Based EM Simulator
HFSS	High Frequency Structure Simulator
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
MICs	Microwave integrated circuits
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System
FDMA	Frequency Division Multiple Access

Chapter 1
Introduction

1.1 Evolution of Wireless Communication

The transmission of information between two or more points that are not physically linked is wireless communication, or often simply wireless. Radio waves are used in the most popular wireless technologies. In the history of communications, the word wireless has been used twice, with a somewhat different definition. It was mainly used from about 1890 for the first radio wave transmission and receiving technology, as in wireless telegraphy, until it was replaced by the modern term radio in 1920. In the 1980s and 1990s, the term was resurrected primarily to differentiate between digital devices that were able to connect without wires. Wireless operations include utilities, such as long-distance communications, which, with the use of wires, are not practical or practicable to introduce. Communication is now changing from generation zero to generation five.

1.2 Zero Generation Wireless Technology (0G)

Wireless phone started with 0G, which might have called Zero Generation, became accessible after the World War-II. At that time, there were only a limited number of communication channels available and mobile operators set up the calls. These mobile devices could be unable to support the feature of handover means Change the frequency of the channel while 0G 1G 2G 3G 4G 5G moving. Zero generation refers to the pre cellular mobile system in the early 1970's. For example, some subscribers had Radio telephones in cars before the introduction of cell phones. Mobile radio telephony system produced modern cellular mobile-telephone technology. These systems are called 0G (Zero Generation) Systems Since they were predecessors of first generation cell phones. 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). The system's users were loggers, construction supervisors, realtors and celebrities. The communication system was used for the purpose of only voice communication [6].

Figure 1.1 Evolution/Enhancement of communication [4].

1.3 First Generation Wireless Technology (1G)

1G is the first-generation wireless telephone technology based on analog signal. They were introduced in 1980 and were called analog cell phones. Nippon Telephone and Telegraph (NTT) introduced the world's first cellular system to be operational in Tokyo, Japan, in 1979. Nordic Mobile Telephone (NMT) and Total Access Communication System were the most popular analog systems in Europe (TACS). Along with these two systems, some other technical company introduced analog systems in 1980’s in Europe. However, the cellular networks systems were not able to interoperate between countries, offered handover and roaming capability [5]. The key downside of First Generation mobile technology is the failure to interoperate between different countries. In addition, 1G has other drawbacks such as low capacity-unreliable handoff system, poor voice links. Also, there was no security since voice calls were used to play back in wireless towers making these calls susceptible to undesirable persons. The first 1G standard in USA 3 was AMPS, launched in 1982. Federal Communication Commission (FCC) allocated a 40 MHz channel within the 800-900 MHz frequency range for this system. AMPS was allocated a supplementary 10 MHz bandwidth, called expanded spectrum (ES) in 1988. Italy, France and UK used communication systems called RTMI, Radio-Comm and

YACS respectively. A telecom standard branded as C-450 was introduced in West Germany, Portugal and South Africa. First Generation system replaced 0G system, whose features includes mobile radio telephones and technologies as Advanced Mobile Telephone System (AMTS), Mobile Telephone System (MTS), Push to Talk (PTT), and Improved Mobile Telephone Service (IMTS).

- Established in 1980s and finalized in early 1990s
- Supported data transfer speeds up to 2.4 kbps
- At first the Advance Mobile Phone System (AMPS) was introduced by the USA and is a first-generation mobile phone system.
- It permits the users to initiate voice calls within only one country [5].

1.3.1 Key features (technology) of 1G system

Key features of 1G system given below-

- Frequency 800 MHz and 900 MHz
- Bandwidth: 10 MHz (666 duplex channels with bandwidth of 30 KHz)
- Technology: Analogue switching
- Modulation: Frequency Modulation (FM)
- Mode of service: voice only
- Access technique: Frequency Division Multiple Access (FDMA)

1.3.2 Disadvantages of 1G system

Disadvantages of the 1G system as shown below

- Voice quality due to poor interference
- Poor life of the battery
- Large mobile phone size (not convenient to carry)
- Less safety (calls could be decoded using an FM demodulator)
- Limited number of users and coverage of cells
- Roaming between similar systems was not possible [1].

1.4 Second Generation Wireless Technology (2G)

2G is the Second-Generation wireless network, established on digital technologies installed in 1990s. 2G was introduced in Finland in 1991. It provided services for instance Short Message System (SMS), picture messages and Multimedia Message System (MMS). As in 2G, text messages and audio signals are encoded digitally, which allows data to be transmitted in such a way that only the requested receiver can receive and decode the data. 2G provides greater security for both sender and receiver. To compress and multiplex Digital signal CODEC (compression decompression algorithm) is used in 2G. TDMA and CDMA were used as digital multiple access technology in 2G system. TDMA splits Signal on time slots whereas CDMA assigns every user distinct Code for Communication a multiplexed way. TDMA technology includes Global System for Mobile Communications (GSM), Personal Digital Cellular (PDC) IS-136, and iDEN in the Digital Enhanced Cordless Telecommunications (DECT) standard for portable mobile phones. GSM was the first 2G System. It is the most popular mobile standard of all mobile devices wireless technologies deployed in worldwide total countries 212. International roaming between different mobile phone operators was introduced first by GSM technology which allows the users to use their mobile phones in many countries. TDMA technology is used in GSM to multiplex up to 8 calls per channel in the 900 MHz and 1800 MHz frequency bands. It delivers voice signals along with circuit switched data at speed up to 14.4 kbps. The FCC also auctioned a new spectrum block in the 1900 MHz band in the USA. Over the last 20 years, this technology has been constantly being developed to provide better services. Some new technologies have been industrialized on the basis of the original GSM, prominent in some advanced systems, identified as 2.5 generation (2.5 G) systems[5].

1.4.1 Key features of 2G system

Key features of the 1G system as shown below-

- Digital system (switching)
- SMS services are possible
- It is possible to roam

- 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
- Limited number of users and hardware capabilities [1].

1.5 GPRS (General Packet Radio Service) 2.5G

2.5G, stands for "second and half generation", is a mobile wireless standard developed in the middle of its predecessor second generation and its successor third generation. The expression "second and half generation" is applied to define the "General Packet Radio Services". GPRS can provide the data rate around 56 Kbit/s to 115 Kbits/s as peak. It supports facilities Such as Access Multimedia Messaging Services (AMMS), Wireless Application Protocol (WAP), and internet facilities including Email and the World Wide Web (WWW) access. The charge for data transfer in GPRS is in traffic megabyte conveyed typically, but in data communication through conventional Circuit switching is being billed each min of linking period [5].

1.6 Third Generation Wireless Technology (3G)

Telecommunication standards group 3G is used to define the third generation of wireless communication standards, overriding 2.5G, and preceding 4G. International Telecommunication Union (ITU) framed a plan to employ the worldwide frequency band of 2000 MHz, which will be able to support a single, ever-present wireless network standard for all countries in the world. The plan is known as "International Mobile Telephone 2000" or IMT-2000 Standard. There are three different types of multi-access technologies-CDMA 2000: proposed by the North American Wireless Telecommunications Standards Group based on the Code Division Multiple Access Technology. Its channel width is 1.25 MHz and speed are up to 144 Kbps.

WCDMA (UMTS): WCDMA FOMA service has been launched in Japan by NTT Do Como. for the first time in the world commercially in 2001. It is developed as a Multiple Access Division of Wide Band Code. Its channel width is 5 MHz and speed are up to 2 Mbps. TD-SCDMA: China wireless Telecommunication standards group proposed the Time Division Synchronous Code Division Multiple Access technology for use in 3G [5]. Third Generation Partnership Project (3GPP) continued that project by formulating a wireless system that achieves the specification of IMT-2000 standards. The third generation or 3G wireless technology came into services in the year of 2000.

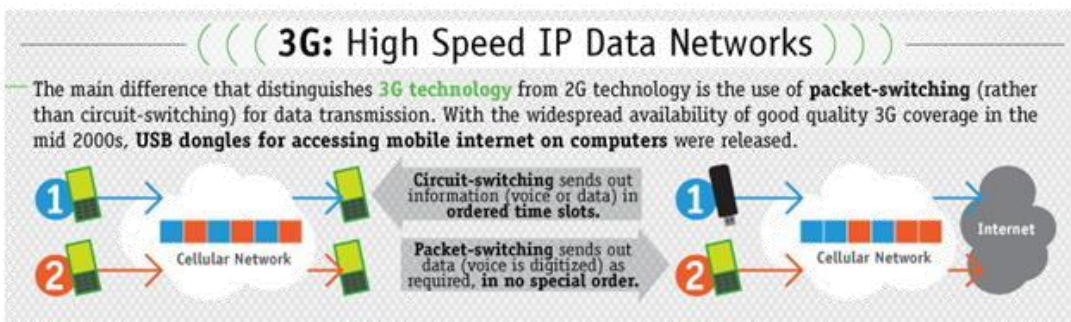

Figure 1.2 3G vs 2G Communication [4]

Previous technology supported data transmission speed of 144Kbps as peak whereas 3G has increased it to 2 Mbps. Smart phone or multimedia cell phone is required to get services of 3G technology. Bandwidth and data transfer rates have been increased in 3G to facilitate web-based applications, audio and video files.

Network operators are enabled offering their user a broader scope of more progressive facilities by acquiring better capacity of network through enhanced Spectral Efficacy with the deployment of 3G technologies. 3G system services comprises of Wide area of wireless voice call, video call, mobile television, Wireless broadband data, GPS service and video conferencing, entirely in portable wireless environment. This network has the improvements over 2.5G network and previous given below [6]:

1. Numerous times higher data transfer speed.
2. Upgraded audio and video streaming

3. Video conferencing facility
4. greater speed in WAP and Web browsing
5. IPTV (TV through the Internet) support

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

Disadvantage of G system is written below -

- ✍ Expensive spectrum licenses
- ✍ Costly infrastructure, equipment’s and implementation
- ✍ Higher bandwidth requirements to support higher data rate
- ✍ Costly mobile devices
- ✍ Compatibility with older generation 2G system and frequency bands [1].

1.7 Fourth Generation Wireless Technology (4G)

The main concept of 4G is inter-operability between diverse categories of networks, to provide high speed data transfer rate for example 100 Mbps as the peak data rate for both the server and the receiver of data which are moving to a speed of 60 Km/h. And the data transfer rate should be a maximum of 1 Gbps when the Server and receiver are stationary; [5]. Comparison of 4G cell phone generation shown in figure 1.3. Currently deployed mobile networks standards are 4G that have replaced third generation- 8 networks in many countries. In a different context, 4G is just an introduction by academics' research. trouble being deployed, and able to meet its predefined performance and throughput. Now We can have access to the internet by using our mobile with the assistance of various technology, like Wi-Max, Wi-Fi, EDGE, WAP, GPRS and Wi-Bro in 3G. But users are facing issue when they have to developments labs to cope with the

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]

limitations and difficulties of 3G, which is having access the internet through the cell phone by using any of these described technologies, the user is stuck when they travel to place where inter-operability in the middle of different networks attains. When using 4G, users are able to access the network using any of the technologies mentioned above, even if they travel from one to another place. The issues thought to have been addressed with the 4G network are as follows:

1. As per high data transfer rates, 4G wireless technology has added an IP feature to the mobile phone for enhanced security purposes.
2. In fourth generation wireless standard, the users can download to a data level of rate 100 Mbps in access to mobile devices and in case of stationary 1Gbps for Local Connectivity of mobile network.

3. OFDMA is a new technology introduced in 4G in place of Hybrid-based technology deployed inside 3G with the mixture of IS-95 and CDMA. OFDMA is more efficient than previous TDMA or CDMA.
4. In OFDMA, data are sent by allocating the channel into a narrow band for better efficiency which is an outstanding feature of fourth generation wireless system.
5. 4G is going to describe as the Wireless Mobile Broadband Access (WMBA) in which it is located IEEE 802.16e processing. This indicates the availability of the internet. To prevent interference with calls in the event of downloading data from any website, the execution is under development. An extra ordinary step in 4G wireless technology is to propose a downlink data rate of 128 Mbps and an uplink data rate of 56 Mbps. The condition of Internet connectivity is the availability of a hotspot, which is the limitation of the service.
6. In Parallel with Worldwide Interoperability for Microwave Access (WiMAX), LTE a wireless system for the broadband access is intended to integrate in 4G mobile phones. There's a comparison in the middle of WiMAX and LTE. LTE is for IP Address and go along with the alike TCP/IP idea assumed from the computer networking architecture. It will supply greater safty as well as high transferability of data, low latency and power to control bandwidth. 4G or LTE is also compatible with CDMA technology so that it can back up data between the two networks.
7. LTE and IEEE 802.16m are the two major wireless standards going to be introduced by 3GPP. Earlier one is approved permission for the more process while it will become a fragment of fourth generation wireless system. IPv6 is permitted as a 4G by edition wireless by default on June 2009 [5].

1.7.1 Key features of 4G systems

Key feature of 4G system is given below.

- ✍ Far greater data speeds of up to 1Gbps
- ✍ Protection and mobility improved

- ✍ Reduced latency for essential applications for missions
- ✍ Video streaming and gaming in high definition
- ✍ Voice over LTE network VoLTE (using Voice IP Packets)

1.7.2 Disadvantages of 4G system

Disadvantage of 4G system is given below.

- ✍ Expensive infrastructure and hardware
- ✍ Expensive Spectrum (most countries, the frequency bands are too costly.)
- ✍ It needs high-end mobile devices compliant with 4G technology, which is expensive.
- ✍ It takes time for large deployment and upgrade [1].

1.8 Fifth Generation Wireless Technology (5G)

Fifth generation or 5G is the next generation of wireless technology standards planned to deploy around 2020. 5G is to facilitate wireless networks by delivering enhanced bandwidth, high data transfer rates and lower latency to a billion number of electronic devices. This is one of the most promoted issues in the world of technology which is promising to facilitate the access to self-driving vehicles, virtual reality (VR), and the Internet of Things (IoT). Telecommunication enterprises or regulation bodies for example 3GPP, WiMAX or ITU-R have not finalized any particular specification or official document for 5G yet.

5G technology is supposed to be the wireless degree of excellence communication systems in cell phone wireless technologies. Wired communication has now come to be almost obsolete. At present Cell phones are a serving as a communication tool and being used for a variety of other uses. Earlier wireless technology is facilitating The ease of exchanging telephones and data whereas fifth generation is bringing in a new level and transforming human life into a true mobile life.

1.8.1 Features of 5G

Feature of 5G is given below

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

This section concludes by with hindsight the upcoming generation of wireless networking technology will also be briefed on current wireless systems in the following table. In the next years these new technologies have a long approach to travel and exciting and amazing features are destined to roll out to come [3]. Table 1.1 shows generation of communication.

1.9 Final thoughts

Wireless technology has been evolving continuously to meet increasing demands and higher requirements for specifications. The telecommunications industry has faced many new challenges in terms of technology, efficient use of spectrum and, most importantly, security for end users since the deployment of first-generation mobile networks. Ultra-fast, feature-rich and highly secure mobile networks will be provided by future wireless technologies [1]

TABLE 1.1 GENERATION OF COMMUNICATION

Generation	Speed	Technology	Time period	Features
1G	14.4 Kbps	AMPS, TACS, NMT	1970 – 1980	Wireless phones are only used for voice during the 1G time
2G	9.6/ 14.4 Kbps	CDMA, TDMA	1990 - 2000	By having multiple users on a single channel through multiplexing, 2G capabilities are achieved. During 2G, cellular phones and voice are also used for data.
2.5G	171.2 Kbps, 20-40 Kbps	GPRS	2001-2004	The Internet is becoming widespread and knowledge is becoming more important. Multimedia and streaming services are beginning to expand. While a small number of mobile phones have this facility, cell phones have begun to support web browsing.
3G	3.1 Mbps, 500-700 Kbps	EDGE, CDMA-200 UMTS	2004-2005	Supports multimedia platforms and streaming together. Worldwide connectivity and movability through various types of system are made possible such as Telephones, PDA's etc.
3.5G	14.4 Mbps, 1-3 Mbps	HSPA	2006 - 2010	To support higher data, it provides higher throughput and speeds.
4G	100-300 Mbps. 3-5 Mbps 100 Mbps (Wi-Fi)	LTE, WiMax, Wi-Fi	Now (Read more about the transition to 4G)	Speeds for 4G are further improved to keep up with the demand for data connectivity used by different providers. 4G also supports high definition streaming. Fresh phones with HD interface capabilities. It's getting pretty cool here. Portability is further improved at 4G. Roaming world-wide is not a distant thought.
5G	1-10 Gbps	Beam forming, Massive MIMO, mm wave	Soon (probably 2020)	There's no 5G technology currently installed. If this becomes available, it will provide customers with very high speeds. It will also make good use of the bandwidth available, [5].

1.10 Global 5G spectrum update

Around the world, these bands have been allocated or targeted

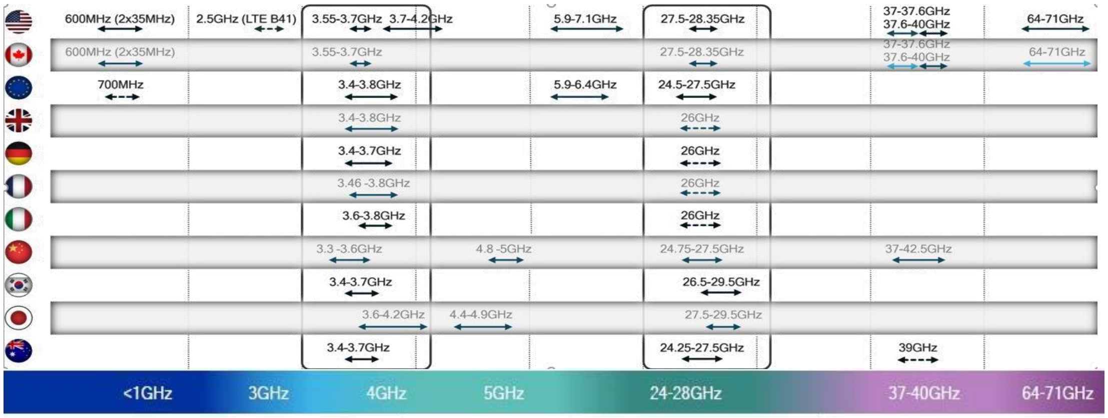

Figure 1.4. Global 5G spectrum [6-7]

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

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

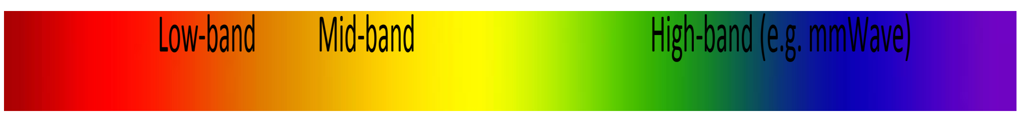

Figure 1.5 5G spectrum [6-7]

1.10.2 Low-band

Broadcast Incentive Public sale

1. A part of the 600 MHz band was fruitfully auctioned that created $19.8 Billion in profits after assignment phase.
2. 70 MHz of licensed spectrum consisting of 2 different channels and another 14 MHz using for unlicensed.
3. Timing of use of spectrum aligns with 5G [6-7].

1.10.3 Mid-band

Residents Broadband Radio Services

1. Initializing a bandwidth of 150 MHz PAL1, GAA2 with a 3.5 GHz band 3-layer swap with incumbents.
2. FCC developed PAL directions in 2017 to create them appropriate for 5G.
3. To effort an LTE-based ecosystem CBRS Alliance was introduced officially.
4. 3.7-4.2 GHz and 5.9-7.1 GHz inquiries was notified by FCC. [6-7]

1.10.4 High-band

Ruling on Spectrum Frontiers in 2016 & 2017 Second Ruling

1. In many mm wave bands, it opens up about 11 GHz.
2. 70 percent of bands released recently are either unlicensed or shared.
3. Consistently agreed. FCC requested for observation on another nominee spectrum branded for IMT-2020.
4. Taking into account the addition of 24.25-24.45, 24.75-25.25 GHz 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

Concentration mid-band on (3.4 GHz–3.8 GHz) and 26 GHz band (24.25-27.5 GHz) To go faster 5G rollout in EU, regulatory activities are driven by EC RSC, CEPT, key European Member States.

- Supervisory the 3.4-3.8 GHz events and 26 GHz are run extremely for auctionspredictable in 2017-2018.
- 5G approach for UK was published by the government in March 2017.
- Ofcom planned on auction 150 MHz channel in 3.4 GHz–3.6 GHz in 2017-2018 and 110MHz channel in 3.6 GHz – 3.8 GHz in 2018-2019.
- For timely 5G organization, Ofcom has introduced a work platform on 26 GHz band accessibility.
- Italian government is expected to auction 700 MHz, 3.6 GHz – 3.8 GHz and 26 GHz – 27.5 GHz in 2018.
- Ireland government successfully auctioned 350 MHz of frequency spectrum for 5G communication.
- Spain government tendered 3.6 GHz-3.8 GHz band permitting to market demands and operators needs in 2018.
- Spain, concentrating on the 26 GHz band. For release in 2018, at least 1.4 GHz of bandwidth is available.

Another countries like Belgium, Austria, Switzerland are organizing to free 2018-2019-time frame range[6-7].

1.11 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.

1.11.1 Frequency

In normal sense frequency means how frequently occurs a particular event in a particular period. Basically, frequency refers to the number of occurrence of an event in a definite time. From the typical definition, “The number of recurrence of a signal over a defined time period (1 second), is known as frequency. Periodic signal repeats itself after every ‘T’ seconds called time period. Frequency of periodic signal is nothing but the inverse of time period (T). In engineering terminology, frequency is used to identify the rate of oscillatory and vibratory occurrences, for example radio waves, audio signal (sound), mechanical vibrations, and light. The SI (International System) unit of frequency which is entitled by the German physicist Heinrich Hertz is hertz (Hz). One hertz denotes that an event or signal repeats once per second.

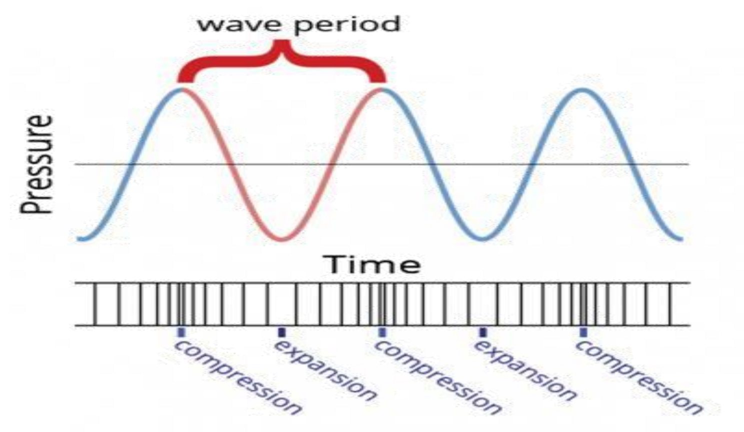

Figure 1.6. Frequency diagram

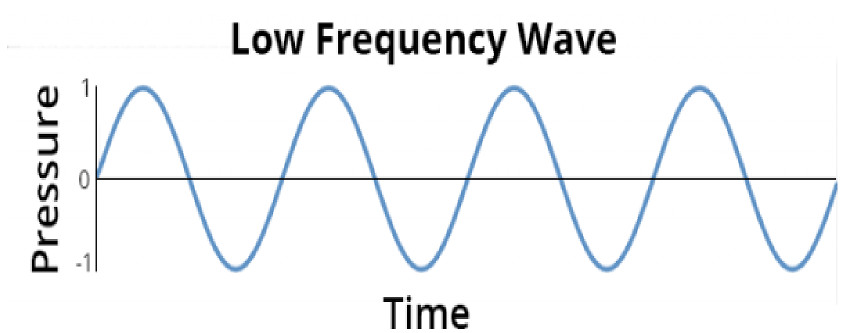

Figure 1.7. High frequency and Low frequency diagram

1.11.2 Bandwidth

In communication systems, bandwidth is defined as the capacity of a wired or wireless communications system link to transmit the maximum amount of data from one point to another over a computer network or internet connection in a given amount of time, typically in one second. In case of antenna, bandwidth refers to the range of frequency over which the antenna can properly radiate or receive energy. Regularly, bandwidth is one of the most desired determining parameters used to decide upon an antenna. For instance, many antenna types have very narrow bandwidths and cannot be used for wideband operation.

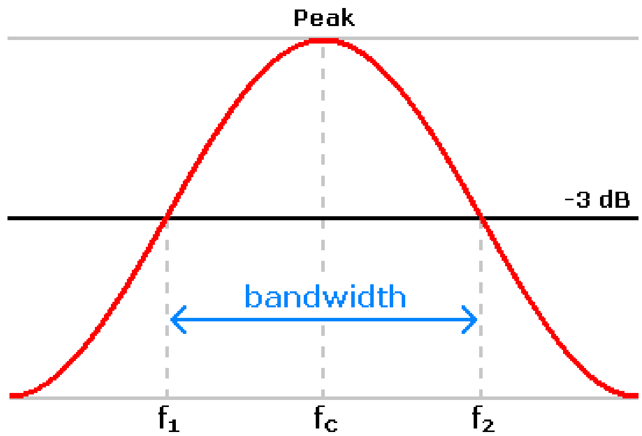

Figure 1.8. Bandwidth diagram

1.11.3 Input Impedance

The input impedance of an antenna is the ratio of the voltage to the current at the antenna input terminals. It is an important parameter of an antenna, which expresses the resonance of the antenna. There are two parts of the input impedance – real and imaginary. The power that is radiated away or absorbed within the antenna is represented by the real part of the input impedance. The power that is stored in the near field of the antenna is represented by the imaginary part of the input impedance which is known as reflected power. A resonant antenna is a one whose real input impedance and zero imaginary impedance. The input impedance of an antenna is determined by the length and size of that antenna. Impedance is denoted by Z, which has a true portion, including radiation resistance of the antenna Rrad and its ohmic losses R ohm, and its reactive portion X[11].

1.11.4 Impedance Matching

According to the standard definition, "The approximate impedance value of the transmitter, when it is equal to the approximate impedance value of the receiver, or vice versa, is referred to as impedance matching." In the case of wireless communication, impedance matching between the antenna and the circuitry is necessary. From the theory of Maximum Power Transfer, when the impedance of the antenna, the transmission line, and the circuitry over a frequency range is referred to as tuning or matching the antenna. The quality of the match is characterized by VSWR, with Bandwidth referring to the range of frequency that the antenna impedance is close to 50 Ohms for a given VSWR. A resonant device is one that produces better output at a certain narrow frequency band. Antennas are resonant devices whose impedance, if matched, delivers better output.

Necessity of impedance matching given below.

1. The power from the source will be effectively delivered to the feedline, if the feedline impedance matches the source impedance.
2. The power from the feedline will be effectively delivered to the antenna, if the impedance of the antenna matches the impedance of the feedline.
3. For the receiver antenna, the output impedance of the antenna should match the input impedance of the circuit of the receiver amplifier.
4. For the transmitter antenna, the input impedance of the antenna should match the output impedance of the transmitter amplifier and the transmission line impedance.

1.11.5 Directivity and Gain

The ability of an antenna to radiate energy in a particular direction when it is transmitted, or to receive better energy from a particular direction when it is received, is called directivity. And gain is generally defined as the ratio of the power generated by the antenna from a far-field source on the beam axis of the antenna to the power generated by a hypothetical lossless isotropic antenna that is equally sensitive to all directions of signals. There is a relationship between gain and directivity. The phenomenon of increased directivity when comparing a light bulb to a spotlight recognizes this relationship. In a specific direction, a 100-watt spotlight can have more light than a 100-watt light bulb and less light in other directions. It can be said the light bulb has less “"directivity" as opposed to the spotlight. The spotlight is close to a high-directivity antenna. The functional benefit of directness is gain. Mathematically gain equals to the multiplication of directivity and efficiency. The relation between gain and directivity includes a new parameter (η) which is known as the efficiency of the antenna [8]. Figure 1.9 shows Directivity and Gain.

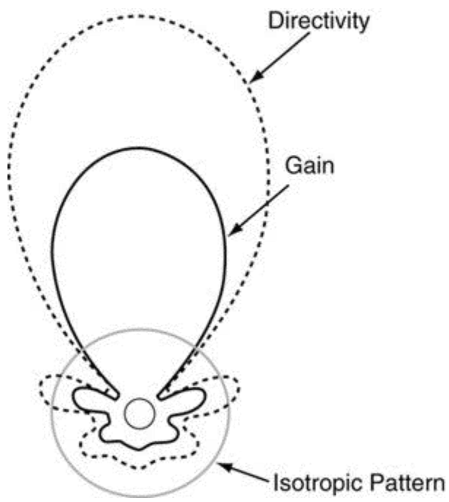

Figure 1.9: Directivity and Gain

1.11.6 Radiation Pattern

The term radiation pattern (or antenna pattern or long field pattern) refers to the directional (angular) dependence of the frequency of the radio waves from the antenna in the field of antenna design. Radiation pattern describes the relative strength of the radiated field at a constant distance in different directions from the antenna. The pattern of radiation is also a "reception pattern" since it defines the antenna's receptor properties as well. The pattern of radiation is three-dimensional, but displaying the three-dimensional pattern of radiation in a realistic way is difficult. Figure 1.10 indicates the pattern of radiation. Measuring the three-dimensional radiation pattern is often time-consuming.

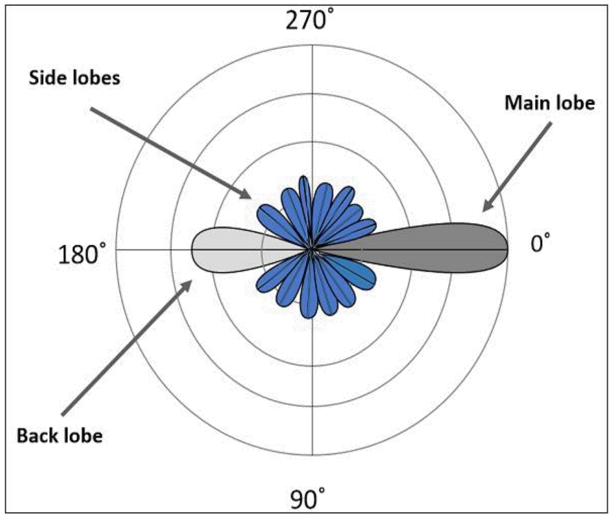

Figure 1.10. Radiation pattern

The calculated radiation patterns are often a slice of a three-dimensional pattern, leading to a two-dimensional pattern of radiation that can be easily seen on a computer or on a piece of paper. Such concept measurements are presented in either a rectangular or polar format [7].

1.11.7 Voltage Standing Wave Ratio (VSWR)

VSWR (Voltage Standing Wave Ratio) is a calculation of how radio-frequency power is transmitted effectively from a power source through a load via a transmission line. In other words, the ratio of maximum power to minimum wave power can be calculated and the standing wave ratio is called (SWR). In term of voltage, the ratio of the reflected voltage over the incident voltage is called VSWR. The VSWR is always an antenna number that is true and positive. The lower the VSWR is, the more the transmission line is matched to the antenna and the more power is supplied to the antenna. In this case, no power is reflected from the antenna, which is the perfect case[7]. The minimum VSWR is 1 The VSWR is shown in Figure 1.11.

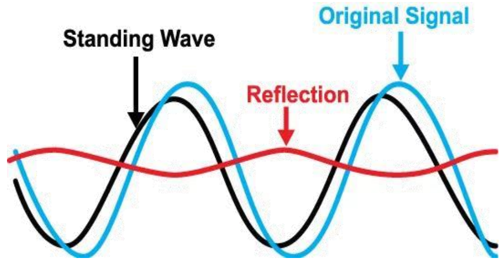

Figure 1.11 VSWR

1.11.8 Return Loss (RL)

The Return Loss of an antenna is a statistic that shows the proportion of radio waves arriving at the antenna input that are rejected as a ratio compared to those accepted. In relation to a short circuit, it is expressed in decibels (dB) (100 percent rejection). Another way to express the mismatch between the antenna and the feedline is return loss (RL). The algorithmic ratio, calculated in dB, contrasts the power reflected by the antenna with the power fed into the antenna from the transmission line. The RL is correlated directly with the VSWR. In practice, the most commonly quoted parameter in regards to antennas is S11. S11 is actually nothing but the return loss (RL). If S11 = 0 dB, then nothing is radiated and all the powers reflected from the antenna. If S11 = -6 dB, this implies that if 3 dB of power is delivered to the antenna, -3 dB is the reflected power. The acceptable VSWR of less than or equal to 2 corresponds to a RL or S11 of -9.5 dB or lower. In this thesis RL of -10 dB is taken as acceptable [11].

1.11.9 Polarization

The antenna's polarization is determined by the electrical wave field emitted by the antenna. Specifically, the electric field's magnitude and phase determine the antenna's polarization. When the magnitudes and phases of the components of the electrical field are equal, the antenna is polarized linearly. The antenna is circularly polarized if the magnitudes are identical, but the phases vary by 90 degrees.

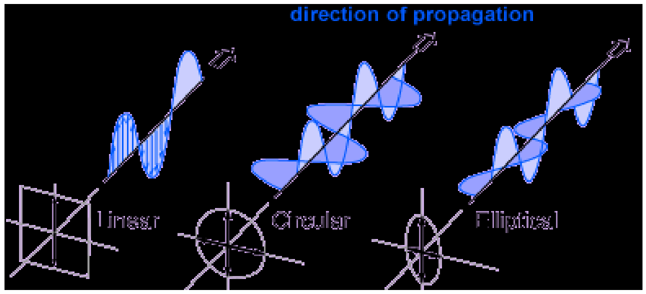

Figure 1.12. Polarization Linear, Circular, Elliptical [12]

Their predicted electrical fields have to be aligned in order for two linearly polarized antennas to interact with each other. A circular polarized antenna, however, can interact independently of its orientation with any linear antenna. Where a circular antenna is insensitive to orientation, a linear antenna radiates higher power since all power is guided in one direction rather than split between the two components. Each form of polarization has its benefit. The reader antenna is either linear or circular depending on the application. Preferably, the tag antenna should be circularly polarized so that it can be read from any direction [12]. Figure 1.12 shows three type of polarization.

1.12 Microstrip Antenna

A microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 1.13. The patch is generally made of conducting material such as copper or gold and can take any possible shape. On the dielectric substrate, the radiating patch and the feed lines are usually photo engraved.

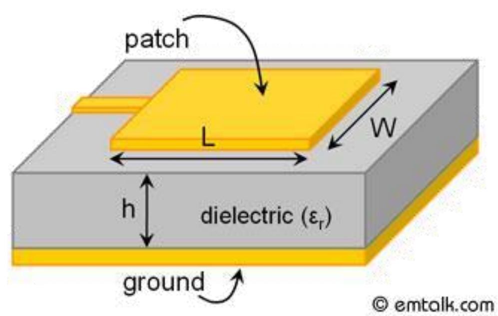

Figure 1.13 A Microstrip Patch Antenna Arrangement [12]

The patch is usually square, rectangular, circular, triangular and elliptical or some other typical shape to simplify the analysis and performance forecast. The length (L) of the patch is normally 0.3333λ 0<L <0.55-0070 in the case of a rectangular patch, where 5-007 is the free-space wavelength. The patch is selected to be very small, so it is t<<0 (where tis the patch thickness). The dielectric substrate height h is typically 0.0035-007-0 ??h 0.055-0070. The substrate dielectric constant (шr) is usually within the range of 2.2 ≤ шr≤ 12. Due to the fringing fields between the patch edge and the ground plane, microstrip patch antennas radiate primarily. A thick dielectric substrate with a low dielectric constant is ideal for good antenna performance, as it provides better efficiency, higher bandwidth and better radiation. This design does, however, contribute to a larger antenna size. Higher dielectric constants that are less effective and result in narrower bandwidth must be used to build a compact Microstrip patch antenna.

1.12.1 Microstrip antenna Feed Techniques

1. Microstrip Line Feed
2. Coaxial / Probe Feed
3. Aperture Coupled Feed
4. Proximity Coupled Feed

1.12.2 Microstrip Line Feeding

The microstripe transmission line is etched directly on the edge of the patch in this form of feeding, which remains the complete structure on the same plane. Figure 1.14 shows microstrip feed line.

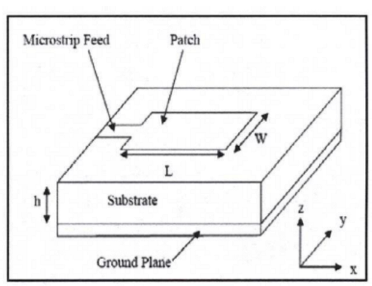

Figure 1.14. Microstrip Line Feeding [11]

1.12.3 Coaxial / Probe feeding

The coaxial connector's inner conductor passes through the substrate and is welded to the radiating patch, while the ground plane is attached to the outer conductor. Coaxial feeding shown in figure 1.15.

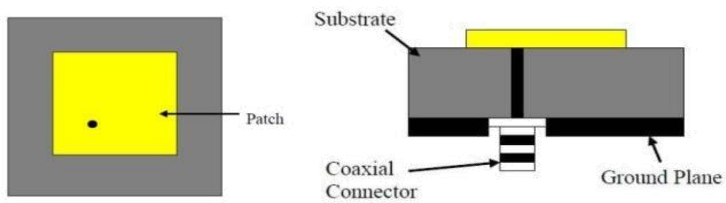

Figure 1.15. Coaxial / Probe feeding [11]

1.12.4 Aperture Coupled Feed

The opening coupling consists of two substrates separated by a ground plane within this form of feed. The ground plane at the bottom of the lower substrate divides the radiating patch and the microstrip line. The coupling is accomplished in the ground plane by an electrically small aperture or a slot cut. Figure 1.16 shows aperture-coupled feed.

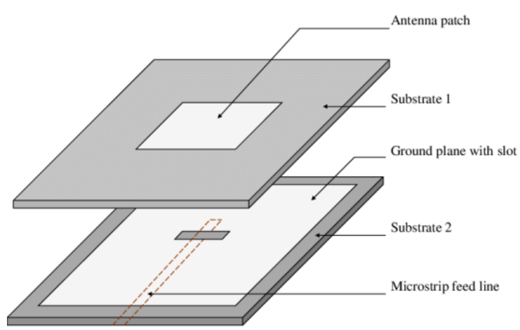

Figure 1.16 Aperture-Coupled Feed [11]

1.12.5 Proximity Coupled Feed

It's also called Electromagnetically Coupled ECMSA. It is composed of two substrates, too. The feed line of the microstrip is situated between two substrates and at the top of the upper substrate is the radiating patch.

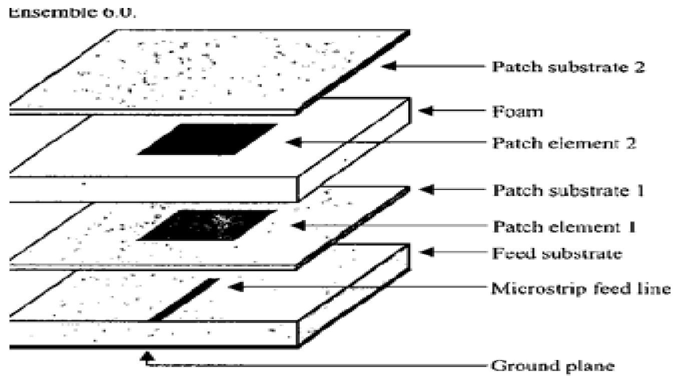

Figure 1.17. Proximity-Coupled Feed [11]

1.12.6 Advantages and Disadvantages of Microstrip Antenna

Thanks to their low-profile construction, microstrip patch antennas are growing in popularity for use in wireless applications. They are also highly compatible with embedded antennas in wireless handheld devices, such as mobile phones, pagers, etc. The telemetry and contact antennas on missiles must be small and conformal and are also patch antennas for microstrips.

Some advantages of the microstrip antenna are given below:

1. Microstrip antennas are lightweight and low volume.
2. They can be manufactured at a low cost and can therefore be produced in large quantities.
3. They have a low-profile planar configuration that can be easily adapted to the host surface.
4. Supports both linear polarization and circular polarization.
5. Microstrip antennas can be easily integrated with integrated microwave circuits (MICs).
6. They're capable of dual and triple frequency operations.
7. They are mechanically robust when mounted on rigid surfaces.

Some disadvantages of the Micro-strip antenna are given below:

1. Microstrip antenna has narrow bandwidth.
2. Their efficiency is low.

3. They are of low gain.
4. They suffer from external radiation from feeds and junctions.
5. Poor end fire radiator except for tapered slot antennas.
6. Their capacity for handling power is low.
7. Surface wave excitement

There is a very high-quality antenna for microstrip patch antennas (Q). Q reflects losses related to the antenna and a broad Q contributes to low bandwidth and low performance. By increasing the thickness of the dielectric substrate, Q can be decreased. But an increasing fraction of the total power supplied by the source goes into the surface wave as the thickness increases. This contribution of the surface wave can be counted as an undesired power loss as it is gradually distributed in the dielectric bends and causes the characteristics of the antenna to deteriorate. [12].

1.13 Design Tool

1.13.1 CST Microwave Studio

CST MICROWAVE STUDIO (CST MWS) is a high-quality means of electromagnetic 3D high frequency simulation. CST MWS allows the user to quickly and reliably evaluate high-frequency components, such as antennas, filters, couplers, planar and multi-layer structures, and SI and EMC effects. Both solvers for the time domain and solvers for the frequency domain are available in the software. More solver modules are dealt with by CST for particular applications. Import filters for complex CAD files and extraction of SPICE parameters improve design possibilities and save time. For electromagnetic design and analysis, CST provides precise, effective computational solutions. Our user-friendly 3D EM simulation program helps you to select the most suitable approach for designing and optimizing systems that work across a wide range of frequencies.

1.14 Motivation

Due to its cost-efficiency, versatility, mobility and many other features, it has become very popular since the start of wireless communication. As a result, there has been a rapid increase in demand for mobile connections, data rates and mobile data traffic over the last three decades. Again, a new dimension has been applied to these demands by the Internet of Things (IoT). In almost every decade, the telecommunications industry has evolved from different generations of standards to meet this growing demand. As a result, the 5th generation (5G) is planned to meet the connectivity requirements of more than 100 billion wireless devices, low millisecond latency, 10 Gbps data rate, Internet of Things, etc. that were introduced in the early 2020s [1]. One of the key challenges for the deployment of 5G is the path-loss in high frequency which motivated us to design an antenna that can cope with this challenge.

1.15 Essence

The industry of telecommunication is evolving rapidly. There is coming a new generation in almost every 10 years. 5G is the preceding one, which is of utmost interest for the researchers. Technologies have jumped from the fourth generation (4G) to the fifth generation with the massive rise of wireless apps (5G). The next 4G/IMT-Advanced specifications to be adopted by wireless networking standards are 5G. 5G has a high capacity than the existing 4G and would provide wireless network users with a higher density, allowing the system to provide ultra-reliable connectivity and large-scale computer, as well as the Internet of Things (IoT). As wireless communication is not possible without the employment of antenna, we need to design antennas having 5G compatibility. For antenna design, the microstrip patch antenna is the most popular antenna in wireless communication today due to its unique characteristics. This type of antenna is smaller in size and will therefore provide small end devices. It is possible to etch antennas based on microstrips on any PCB easily. There are various types of microstrip patches, e.g. rectangular, circular, triangular etc. They have lower costs for processing, because they can be mass-produced. They are able to support several frequency bands (dual, triple). They accept dual polarization forms in both linear and circular. By weight, they're light.

For connectivity, the new 4G network uses sub-6-GHz bands. The spectrum resources of these bands available, however, cannot support the requirements of 5G[1]. So, we need to switch to bands ranging from 6 to 300 GHz with higher frequencies. As a result, the following bands were declared by the Federal Communications Commission for 5G wireless communication, including 3.4-3.6 GHz, 5-6 GHz, 24.25-27.5 GHz, 37-40.5 GHz and 66-76 GHz[2] bands, and 27.5-28.35 GHz for 5G[2] bands[1]. Several researches were performed on designing high gain microstrip patch antenna for 5G communication at 28 GHz [4-9]. But some of those antennas do not cover the whole of 28 GHz bands as declared by FCC while others are not compatible with 5G mobile phone due to their large size. So it is of utmost need to design an antenna that will cover the 28 GHz band and compatible with 5G smartphone.

Chapter 2
Literature Review

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

Members periodically meet to team up and develop cellular connectivity requirements for the 3rd Generation Partnership Project (3rd Generation Partnership Project). The norms for 5G are currently established by 3GPP. Some 5G criteria based on the achievement of three main performance metrics have been proposed by the International Telecommunications Union (ITU) (KPIs) [8]:

- Peak data speeds of >10 Gbps for improved mobile broadband (eMBB)
- >1M/km2 link for massive communications of the system kind (MMTC)
- <1ms of latency for low-latency, ultra-reliable contact (URLLC)

An overview of the basic technical specifications set out as minimum requirements for 2020 is given in the table below.

TABLE 2.1. TECHNICAL REQUIREMENTS OF 5G [8]

Metric	**Requirement**	**Comments**
Peak rate of data	UL: 10 Gb/s DL: 20 Gb/s	Single mobile eMBB in optimum conditions, assuming all the services used
Spectral performance peak	UL: 15 b/s/Hz DL: 30 b/s/Hz	Single mobile eMBB in optimum conditions, assuming all the services used
Data rate encountered by the user	UL: 50 Mb/s DL: 100 Mb/s	5 percent CDF of the throughput of the eMBB user
Capacity for area traffic	Indoor hotspot DL: 10 Mb/s/m2	eMBB
Latency of the Consumer Plane	eMBB: 4 ms URLLC: 1 ms	Single users for the DL and UL tiny IP packets (eMBB and URLLC)
Plane Latency Management	20 ms (encouraged to consider 10 ms)	Transition to active from idle (eMBB and URLLC)
Density of Relation	1 M devices per km2	For mMTC
Reliability	99.9999% success prob.	32 L2 bytes within 1 ms at cell edge
Bandwidth	>100 MHz; up to 1 GHz in > 6GHz	Enabled Carrier Aggregation

TABLE 2.2 DEFFERENCES BETWEEN LTE AND NR [8]

	LTE	NR
Frequency of Operation	Up to 6 GHz	Up to 6 GHz, ~ 28 GHz, ~ 39 GHz, other mm Wave bands (Up to 52 GHz)
Carrier Bandwidth	Max: 20 MHz	Max: 100 MHZ (at < 6 GHz) Max: 1 GHz (at > 6 GHz)
Carrier Aggregation	Up to 32	Up to 16
Analog Beamforming (dynamic)	Not Supported	Supported
Digital Beam Forming	Up to 8 Layers	Up to 12 Layers
Channel Coding	Data: Turbo Coding Control: Convolutional Coding	Data: LDPC Coding Control: Polar Coding
Subcarrier Spacing	15 kHz	15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz
Self-Contained Sub Frame	Not Supported	Can Be Implemented
Spectrum Occupancy	90% of Channel BW	Up to 98% of Channel BW

It is a large responsibility to define an intact new standard for 5G. 3GPP has fragmented the 5G standardization into two different releases: Release 15, which relates to NR Phase 1. and Release 16, which relates to NR Phase 2. The common components between LTE and NR, such as both using orthogonal frequency division multiplexing (OFDM) are included in NR Phase 1. However, there are also differences between LTE and NR as summarized in Table 2.2

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 version (NSA) that uses the current LTE core, and a standalone version (SA) that uses the NR core and is entirely released from the core LTE network. Some new terminology has been announced to keep straightforward which devices can communicate with each other [8]:

- LTE eNB—A device that can be connected to the Evolved Packet Core (EPC) or to the ESP. The current core LTE networke
- LTE eNB—Evolution of the LTE eNB that can be connected to the EPC and the NextGen core.

- gNB —5G New Radio (NR) equivalent of the LTE eNB
- NG—Interface between the NextGen core and the gNB
- NG2—Control plane interface between core network and RAN (S1-C in LTE)
- NG3—User plane interface between the core network and RAN (S1-U in LTE)

Table 4 presents the operating frequency bands proposed in the RAN4 meeting held in May 2018. It is important to note that band n261 has been added and, more remarkably, band n259 defined in the old versions as 31.8 GHz–33.4 GHz Time Division Duplex (TDD) has been removed. This band was originally called as a study band, but CEPT removed it for 5G in November 2017.

TABLE 2.3 FREQUENCIES OF INTEREST IN SEVERAL LOCATION [8]

NR Operating Band	Uplink (UL) and Downlink(DL) Operating band BS transmit/receive UE transmit/receive FUL _low-FUL _ high FDL _ low – FDL _ high	Duplex Mode
n257	26,500 MHz – 29,500 MHz	TDD
n258	24,250 MHz – 27,500 MHz	TDD
n260	37,000 MHz – 40,000 MHz	TDD
n261	27,500 MHz – 28,350 MHz	

Other bands are being carefully researched for use in 5G NR, such as 24.25 GHz-29.5 GHz. In Technical Report 38.815 this frequency update is being tracked and actively reported. A better visual outline of the frequencies of interest in several locations, taken from that technical report is provided in the following frequency chart.

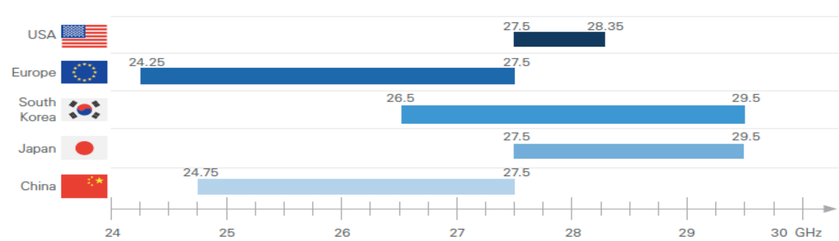

Figure 2.1. Allocated Frequency bands in different locations [8]

2.2 Paper Review

The work of other researchers related to this thesis "Design and Simulation of a Multiband Patch Antenna for 5G Wireless Communication" will be reviewed in this section. This is a critical element for active research on an existing antenna's fifth generation (5G) mobile application. Therefore, with enhanced efficiency and ease of development for the design and simulation of an antenna.

1. Analysis document on, "Design of Dual-Band Metasurface Antenna."

In this paper, it proposes a metasurface antenna for dual-band service in wireless 5G systems. A single-layered square patch array consists of the metasurface excited by two microstrip feeding slots cut into the ground. The metasurface patterns is optimized by using the characteristic mode analysis for the operation of dual-band. At 30 GHz, 38 GHz, and 41 GHz, the metasurface modes resonate. The engraved slots on the ground are resonant as well, to maximize the bandwidth. Over the frequency ranges of 23.75-28.8 GHz and 36.22-40.5 GHz with a good impedance match, the return loss is good. Over the 28 GHz and 38 GHz bands, the simulated gain reaches 8.8-10.17 dBi and 9.46-12.6 dBi. [9].

2. Analysis document on, "Dual-Port 28 GHz Pattern Reconfigurable Quadruple Parasitic IFA Design for MIMO 5G Mobile Terminal."

In this research, a pattern reconfigurable Quadruple Parasitic Inverted F Antenna (QPIFA) for Fifth Generation (5G) MIMO mobile terminal for operating in 28 GHz is suggested. To facilitate the reconfiguration of the pattern, a powered cross-patch antenna was used, surrounded by four parasitic inverted F antenna components.The IFA parasitic elements are used to alter the path of the beams of radiation and the guided cross-patch antenna connects to the metal shortening of the PIN diodes. At port 1 and port 2 four types of combinations between the antenna of the powered cross-patch and the parasitic portion of IFA produce eight different directions of the beam. The four IFAs obtained a maximum realized gain of 9.13 dB, 9.81 dB, 8.65 dB and 7.11 dB. A reflector coefficient of less than 20dB was achieved by the proposed MIMO antenna. Moreover, high insulation between

2 QPIFAs decreases the reciprocal coupling resulting in a coefficient of envelope correlation (ECC) of less than 0.01. The proposed MIMO antenna is considered sufficient for potential 5G mobile terminal applications, in addition to its reconfigurable capacity pattern and low ECC[10].

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

In this paper, dual band single element, two elements, four elements and six elements array antennas are proposed. The results show that the designed 5G antenna array has dual-band response at 28 GHz and 38 GHz bands. The simulated gain of single element antenna is 5.75 dBi and 7.23 dBi at 28 GHz and 38 GHz respectively. For a six element array, the highest gain is obtained. The gain would be 7.47 dBi and 12.1 dBi. The addition of the radiating elements (array) of the antenna thus affects the antenna gain[11].

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

In this work, A 2x4 array was planned and evaluated for a dual-band millimeter wave antenna operating at 28 GHz and 38 GHz. In a 2 ?? 4 square configuration, the proposed antenna array consists of 8 components with 8 ports. Using the slotted patch process, dual-band features have been developed. The antenna gain is contrasted with the techniques of the waveguide and the SMA port feed. It demonstrates that in the case of the SMA port, the antenna array gain is 15.8 dBi at 28 GHz and 13.9 dBi at 38 GHz. With the SMA port, there was a small reduction in antenna gain compared to the waveguide feed. To cover the 28 GHz and 38 GHz bands, all 8 antenna components have very consistent return-loss (S11) characteristics. In addition, each element has a very good separation between the two, which means that the security between its feed point is greater than 28,692 dB at 28 GHz and 38,779 dB at 38 GHz, which complies with the requirements for inter-element protection[12].

5. Analysis document on, “Slot-Based Connected Antenna Arrays for 5G Mobile Terminals.”

In this work, an attractive and compact in size array antenna design using the idea of connected antenna arrays (CAA) is proposed. Compared to conventional ones the CAA technique provides wideband antenna responses which is very suitable for millimeter wave applications and provides more compact-size antenna that can be integrated within mobile phone terminals. In this work a slot based connected antenna array is proposed for standard size mobile handset terminals which includes a 4G frequency band as well as a 5G millimeter wave band antenna systems. The 4G bands covers the frequency between 1.8-3.1 GHz and the 5G band covers the frequency between 27.2-28.5 GHz [13].

6. Analysis document on, “Substrate Integrated Gap Waveguide Circularly Polarized Slot Antenna.”

In this paper a broadband aperture circularly polarized antenna based on substrate integrated gap waveguide (SIGW) for 5G millimeter wave applications is proposed. An inclined aperture is fixed on the metal layer of the SIGW and excitation is provided by microstrip transmission line of SIGW. Circularly polarized radiation mechanism is evaluated shortly. The simulated results demonstrate 10 dB-bandwidth from 24.8 to 31.7 GHz and 3-dB axial ratio bandwidth from 27.3 to 28.8 GHz [14].

7. Analysis document on, “Radiation Performance Analysis of 28 GHz Antennas Integrated in 5G Mobile Terminal Housing.”

In this research paper, several candidate in a 5G mobile terminal, 28 GHz antenna elements are integrated. The radiation characteristics of the considered 5G antenna elements hurts from the terminal housing effects. At first the effects of guided waves, superstrates, surface currents, and the mobile user’s hand on 5G millimeter wave mobile phone antennas are identified and evaluated independently. Using the inverse source technique, the EQCs are obtained which provide a new perception of assisting 5G mobile phone antenna design in MHTE. Between measurement and simulation good agreement is obtained of EQCs. Through the coverage efficiency and the proposed effective beam-scanning efficiency, terminal housing effects on array and subarray performance are assessed. 5G mobile phone antenna design requires to take these effects into attention. The effective beam-scanning efficiency, in common with the coverage efficiency, can be advantageous performance indicators for 5G beam-scanning mobile phone terminals [15].

8. Analysis document on, “Broadband Elliptical Slotted Patch Antenna for 5G Communications.”

In this paper, an elliptical slotted broadband patch antenna for future 5G communications is proposed. The size of the proposed antenna 4.2×4.2 mm2 and the height is 0.127 mm. A rectangular ground with the elliptical slot and T shaped slotted patch is combined with a 50 ohm microstrip transmission line feeding technique is designed. The designed antenna covers the whole band from 22 GHz to 48 GHz which consists of three 5G frequency band, with appropriate gain and also obtained omnidirectional radiation pattern. The designed antenna array realized a high gain of nearby 18 dBi at 28 GHz and 21 dBi at 38 GHz. The proposed antenna in this paper can be a good candidate for upcoming 5G wireless communication [16].

9. Analysis document on, “Design of a Tri-Band Microstrip Patch Antenna for 5G Application.”

In this article, a triple band microstrip patch antenna is proposed for future 5G wireless communication. The antenna substrate is used by Rogers RT Duroid-5880, which has a low relative permittivity of 2.2 and a thickness of 0.25 mm. Two separate commercial electromagnetic simulation applications, namely IE3D and HFSS, designs and simulates the expected antenna and compares both results. Simulation results show that at three 5 G bands, the built antenna provides a reflection coefficient of better than 10 dB. At 24.4 GHz, 28 GHz and 38 GHz, the maximum gain is 6.65 dBi, 7.02 dBi and 5.05 dBi [17].

10. Analysis document on, “Empty Substrate Integrated Waveguide Slot Antenna Array for 5G Applications.”

Based on a unique structure of Empty Substrate Integrated Waveguide (ESIW) a slot array antenna is introduced in this research. The designed antenna delivers a low-loss and highly efficient performance operating at 28 GHz band. It has enhanced the viability of practical application in mobile phone in a way that is cost-effective and comparatively minor complexity in the planar design and modelling of antenna and integration in the mobile phone. A 10 dB bandwidth of approximately 2.9 GHz explicitly supports the proposed antenna from 26.5 GHz to 29.4 GHz. At 28 GHz, the peak gain achieved is 11.6 dBi [18].

11. Analysis document on, "Compact Size MIMO Amer Fractal Slot Antenna for 3G, LTE(4G), WLAN, WiMAX, ISM and 5G Communication."

In this paper, A multiple input, multi output (MIMO) antenna with four ports is proposed as the Amer fractal slot antenna. The Amer fractal slot structure was used in the design of the proposed MIMO to provide several surface current paths, where each path generates its own resonant frequencies, which together achieve a broad operating band. Some of these paths are perpendicular to each other, resulting in circular polarization characteristics, low reciprocal relation for all operating bands (almost 1.5-30 GHz) between opposite ports (1 and 3, 2 and 4), and less than-10dB for all adjacent frequency band ports (almost 1.5-30 GHz) (15-30 GHz). Measured performance ranges from 50 percent to 85 percent in compact size, and low profile. Thus, several wireless networking devices such as 3G, LTE (2.6/3.5 GHz), Wi-Fi (2.4/5GHz), WiMAX (2.5/3.5/5 GHz), ISM (24/5 GHz) and 5G can be supported by the antenna. (GHz 5-6 and GHz 27-28) [39].

12. Analysis document on, "Single-feed Dual-band Aperture coupled Antenna for 5G Application".

In this paper, A lightweight, high-gain, single-feed, dual-band antenna for 5G applications has been proposed for design and simulation. A 28 GHz, 6.25 dBi slot antenna and a 38 GHz, 8.5 dBi patch antenna are part of the planned antenna. Both antennas have a cross-polarization frequency of less than 48 dB and an estimated 2 GHz bandwidth [31].

13. Analysis document on, "Reconfigurable Slot Antenna Design for 5G Smartphone with Metal Casing".

For the fifth generation (5G) smartphone software, a reconfigurable slot antenna has been suggested in this paper to cover a broad bandwidth of 824-960 MHz, 1710-2690 MHz, 3300-3600MHz and 4800-5000 MHz. In all the necessary bands, the proposed antenna has achieved good impedance bandwidth and reasonable total performance. The result indicates that a 5G smartphone with a metal casing is a successful candidate for the proposed antenna [33].

14. Analysis document on, "Eight-Antenna Array in the 5G Smart-phone for the Dual-Band MIMO System".

A compact dual-band slot antenna for forming multiple-input multiple-output (MIMO) antennas has been presented in this paper. Two wide operating bands for 5G mobile communication are shown by the proposed antenna. The antenna displays good efficiency and the MIMO system running in the operating band accepts ECCs (3.3-3.6 GHz and 4.8-5.0 GHz) [32].

15. Analysis document on, "5G mm-wave Antenna Array Based on T-slot Antenna for Mobile Terminals".

In this paper, A phased-array antenna system that can be used in mobile terminals is proposed based on the T-slot antenna. The T-slot antenna's return failure, radiation and scanning behaviors are discussed. The antenna gain of the T-slot antenna is more uniform compared to the usual rectangular slot antenna, so it is more suitable for the 5G mm-wave mobile terminal use [35].

16. Analysis document on, "Design of a Dual-band MIMO Antenna for 5G Smartphone Application".

In this paper, a dual-band four-antenna MIMO array for 5G mobile apps is suggested. Four antennas operating at 3300-3600 MHz and 4800-5000 MHz constitute the proposed antenna. In line with the trend of a full-screen smartphone antenna design, the proposed antenna is positioned in the side frame, on the premise of the reflection coefficient to meet the requirements, to achieve a reasonably high isolation, the antenna size is relatively small, suitable for ultra-thin smartphone communications today [34].

17. Analysis document on, "60 GHz Array Antenna for mm-wave 5G wearable Application".

In this paper, A 60-GHz array antenna is proposed for wearable applications for mm-wave 5G. For broad coverage of radiation, the proposed antenna has a fanbeam radiation pattern. 38.9 dB and 142.9 dB, respectively, are the simulated 3-dB and 10-dB beamwidths in the xz-plane. The radiation properties of the antenna on the phantom of the human head are well preserved, even though the beam is steered. The proposed antenna could be a successful candidate for wearable applications with 60 GHz 5G [36].

18. Analysis document on, "Printed Millimeter-wave MIMO-Based Slot Antwnna Arrays for 5G Networks".

In this paper, For future 5G networks, a simple mm-wave MIMO slot antenna system has been developed, consisting of two, three-element metal arrays. To lower the back radiation and increase the F/B ratio, the EBG reflector was used. A performance analysis was used to explain the design evolution of the proposed MIMO antenna system. Results show that over a broad impedance bandwidth of more than 81.7 percent, the proposed design exhibited high insulation, ranging from 22.5 to more than 50 GHz for 10 dB return loss, and provides low envelope correlation values over the entire operating band, while peak gains were greater than 11.5 and 10.9 dBi at 28 and 38 GHz respectively. The proposed antenna is competitive for future 5G networks because of its compact size and reasonable performance [37].

19. Analysis document on, “Single Feed Compact Millimeter Wave Antenna for Future 5G Applications.”

In this research, a single-layer compact planar antenna has been proposed for upcoming 5G wireless transmission applications, printed on a low-cost dielectric substrate (RTduroid 5880) and resonating at two frequencies- 28 GHz and 38 GHz. The finite element method (FEM) of Maxwell's electromagnetic equations and the parametric study conducted showed the performances as peak gain 8.05dB, bandwidth 921MHz at 28 GHz band and peak gain 8.28dB, bandwidth 1.0451 GHz at 38 GHz band. In addition, bandwidths for both resonance frequencies improve significantly by the idea of merging unwanted narrow bandwidths [19].

20. Analysis document on, "Small Form Factor PIFA Antenna Design at 28 GHz for 5G Applications."

This paper presents the design and study for potential 5G Mobile applications of the lowest form factor planar Inverted-F Antenna at 28GHz. For the feeding and shorting of the antenna, metallic strips are used. This antenna's essential features are its small footmark (0.25λg), 4.5dBi gain, 1.55 GHz impedance bandwidth of 10 dB and 94 percent radiation efficiency. 0.25λg is the sum size of the PIFA antenna. The efficiency of PIFA antennas relies greatly on the size of the ground plane and its location on the ground plane. When located at the corner or side, it displays a strong radiation pattern. The PIFA antenna is mounted on a FR-4 substrate 0.8 mm thick. To enhance the bandwidth, it is possible to add additional parasitic elements [20].

21. Analysis document on, "A SAR Reduced Mm-Wave Beam-Steerable Array Antenna with Dual-Mode Operation for Fully Metal-Covered 5G Cellular Handsets."

In this paper, a reduced 28 GHz beam-driven array antenna with dual-mode operation for a fully metal-coated fifth generation (5G) cell phone is proposed with a specific absorption rate (SAR). The antenna proposed consists of two subframes, each with eight components of the rotating antenna arranged on the upper frame and on the phone's back cover. Subarrays are selected by means of a switch according to the modes. In the frequency band ranging from 27.2 to 28.2 GHz, the proposed array shows strong reflective coefficients and the mutual couplings between the antenna elements are less than-11,8 dB.

There is strong beam control and hemispheric beam coverage for the proposed antenna. The determined peak SAR values on the head phantom are 0.53 and 0.88 W/kg for the beam scan angles of 0 ° and 40 °, respectively, while the input power of each subbarray is 24 dBm[21].

22. Analysis document on, "Compact and Low-Cost 3D-Printed Antennas Metalized using Spray-Coating Technology for 5G Mm-Wave Communication Systems."

This paper introduces proposals that use low-cost EMI/RFI spray-coating technology to metalize high-gain, powerful and lightweight 3D-printed antennas. By using EMI/RFI conductive paint, the manufacturing costs of the antenna and the complexity of the manufacturing process are minimized, while the antenna provides an acceptable 28 GHz band output. Finally, in this study, the novel manufacturing approach offers the proposed antenna to be a probable candidate for potential low-cost 5G mm-wave applications[22].

23. Analysis document on, "A Millimeter-Wave Connected Antenna Array for 5G Applications."

For high data rate future 5G wireless communications, a wide-band novel printed wired antenna array architecture is proposed in this paper at 28 GHz band. The architecture of the antenna to be used for cell phone applications was planar, compact and thin. It produced peak gain ranges from 4.29 dBi to 6.68 dBi using 4 ?? 4 Butler matrix for 4 switched beam positions [23].

24. Analysis document on, "A Novel Connected PIFA Array with MIMO Configuration for 5G Mobile Applications."

A novel Connected PIFA multiple input multiple output antenna has been demonstrated in this work for upcoming 5G wireless applications. The antenna is contained of four MIMO antenna each of which consists of 8-element connected antenna array. Again, each array is formed with eight connected printed Inverted-F antennas (PIFA). The return loss graph shows that the antenna operates at 28 GHz 5G band with the bandwidth of around 1 GHz. The peak gain is 12 dBi and the radiation efficiency is 85% [24]

25. Analysis document on, "Modified Triple Band Microstrip Patch antenna for Higher 5G bands."

This paper presents the design of a modified three-band microstrip patch antenna for Higher 5G bands operating at 28 GHz. The antenna is designed to be 30x40x1.6 mm wide on a substratum of RT/Duroid 5880 with a dielectric constant of 2.2. The proposed configuration of the antenna resonated at 28 GHz, 31.45 GHz and 34.6 triple frequencies with-12.5114 dB,-16.5928 dB,-15.7107 dB return loss and covers-10 dB impedance bandwidth of 1.37 GHz (27.47-28.84 GHz) at 28 GHz, 0.11 GHz (31.38-31.49 GHz) at 31.45 GHz and 34.6 GHz (33.59-36.01 GHz) covering the higher band of 5G mobile applications. In addition, the overall gain of 3,7308 dB and VSWR of 1,6206 is less than 2 and is suitable for a high-frequency antenna to be used in the USA, Korea and Japan with a minimum signal loss of 28 GHz [25].

26. Analysis document on, "A Novel 28 GHz Beam Steering Array for 5G Mobile Device with Metallic Casing Application."

For potential fifth generation mobile device applications, this communication introduces the architecture of a modern realistic 28 GHz beam steering array antenna. The proposed array antenna consists of 16 cavity-backed slot antenna components assembled via the mobile device's metallic back enclosure, in which two eight-step arrays are placed on the left and right edges of the mobile device. A beam steering on the broad side can be produced by each 8-element phased array and a gain of >15 dBi can be achieved at boresight. Approximately 27.5-30 GHz was the measured 10 dB return loss bandwidth of the proposed cavity-backed antenna features [26].

27. Analysis document on, "Compact Quad-Mode Planar Phased Array with Wideband for 5G Mobile Terminals."

In this paper, for 5G mobile terminals, a quad-mode end-fire planar phased antenna array with a wide angle of scanning and 1,2 mm clearance is proposed. The proposed antenna may have an impedance bandwidth of more than 8 GHz. This paper proposes to efficiently combine a multimode array element with different radiation patterns for each mode into a phased antenna array. Similar and wide embedded radiation patterns for all four modes are obtained in the array. In addition, this paper provides for a coaxial to differential stripline transition. The structure of the differential feed is very compact and uses the MMPX connector and vias only. In the range of 25 GHz to 33 GHz, the total scan pattern and coverage efficiency of the measured and simulated phased array antenna is determined and good agreement between the measured and simulated results is observed.. The mean efficiency of the coverage along the frequency spectrum is very similar, but the measurements observe slight variations in the variance of the coverage efficiency. In the frequency range chosen, the coverage efficiency of around 50 percent is achieved for a threshold gain of 5 dBi [27].

28. Analysis document on, “28/38-GHz dual-band millimeter wave SIW array antenna with EBG structures for 5G applications.”

It is proposed to construct a linearly polarized antenna/array dual-band integrated waveguide (SIW) running on the Ka-band. The single feature of the antenna consists of a SIW cavity etched on one of the aircraft with two longitudinal slots. At 28 GHz and 38 GHz, respectively, the longer and shorter slots resonate. The simulated outcomes can only be presented. Using industry standard program, CST Microwave Studio, all simulations were carried out. An impedance bandwidth (S 11 <;-10 dB) of 0.45 GHz (1.60 percent) and 2.20 GHz (5.8 percent) is achieved for single antenna components, with a maximum gain of 5.2 dBi and 5.9 dBi at 28 GHz and 38 GHz, respectively. A horizontally polarized linear array of four elements (1×4) is designed to achieve high gain. For the antenna array, a 3-dB ilkinson power divider is used for the microstrip line feed network. At 28 GHz and 38 GHz, the impedance bandwidth is 0.32 GHz (1.14 per cent) and 1.9 GHz (5 per cent) with a maximum gain of 11.9 dBi and 11.2 dBi respectively. The low cost/loss substrate, RT/Duroid 5880, is used in the proposed designs [28].

29. Analysis document on, “mmWave Novel Multiband Microstrip Patch Antenna Design for 5G Communication.”

For 5G communication, this paper introduces a new mmWave multiband patch antenna architecture. The 5G mmWave antenna resonates with a maximum bandwidth of 5.5 GHz and 8.67 GHz in the 37 GHz and 54 GHz bands, respectively. The 5G mmWave multiband antenna is designed with features such as light weight, low cost, low profile, high performance and high efficiency using microstripe technology. CST MWS simulation software is used to design the 5G antenna. It has a tiny 7.2 to 5.0 to 0.787 mm3 form factor. A appropriate gain of 5 dBi and 6 dBi respectively has been achieved by the 5G multiband antenna. It can be conveniently integrated and used for 5G networking in smart devices [29].

30. Analysis document on, “Dual-band Microstrip Patch Antenna Array for 5G Mobile Communications.”

This paper presents the specification for dual-band 5G communication for the 8-element microstrip patch antenna (MPA) series. With a scale of 16 ?? 16mm2 at 28 and 38 GHz, the proposed antenna array is compact. By etching the U-shaped inverted slot from the main radiator, dual-band response is achieved. The findings show that for the desired frequency bands, the proposed array is able to provide resonance. In addition, the proposed antenna array displays omni-directional radiation and provides both frequency bands with an appropriate gain[30].

2.3 Summary

The development of dual band patch antenna using slot antenna for different band and others has been performed in several studies. From the current research, it is clear that the most potential and important candidate for 5G wireless communication is among the different millimeter wave bands, as many research has been carried out that encompasses those frequency bands. Again, the most challenging task in 5G deployment is to design a high-gain slot antenna to overcome severe path-loss, sufficient miniature to be able to integrate efficiently and easier to manufacture into mobile phone.

2.4 Objectives

1. To design and simulate multiband patch antenna for future 5G wireless communication for 2.6 GHz and 28 GHz.
2. To optimize the antenna parameters.
3. To compare with the existing an antenna.

Chapter 3
Methodology

3.1 Methodology

Methodology is the one kind of specific procedures or techniques. Mainly, it's used to identify, select, process and analyze information about a topic. An users can also use the term "methodology" in his research paper for the reader to critically evaluate a study's overall validity and reliability. Methodology can be divided into two sections one is qualitative methodology and another is quantitative methodology. If we can say like given example like To understand the views of people regarding an incident that took place, or a candidate running for president, a qualitative approach may be used. In comparison to this, where the research objectives and targets are confirmatory in nature, a quantitative approach is usually used.

3.2 Research Design

The framework can be find out the solution to their research problem is known as the research design. Mainly, a research design is used to find out the research questions. Outline the research resources of a research work. For example, research questions, dependent and independent variables, experimental design and, where applicable, data collection methods, and a strategy for statistical analysis.

Improvement of study for this research:

- Study on evolution towards 4G/5G.
- Study on antenna requirements for 5G.
- Study literature on slot based microstrip patch antenna and existing 4G/5G antennas.
- Study procedure slot based (MPA) antenna design.
- Study antenna design procedure in CST Microwave Studio.
- Calculate appropriate parameters to design antenna.
- Implement the procedure.

- Implement the procedure.

3.3 Pilot Study

A pilot study, pilot project, pilot test or pilot experiment is a small-scale experimental study conducted to determine feasibility, time, cost, hostile occurrences and develop the nature of the study before conducting a full-scale research work. It is done before the research is planned. In general, pilot studies are conducted as planned for the research. Althouhg a pilot study cannot rule out any systematic errors or unexpected problems, it reduces so many errors that the initial study will waste time and effort.

Importance of Pilot study:

- To test the research process and/or protocol.
- To categorize variables of concern and elect how to functionalize each one.
- To develop or examine the effectiveness of research instruments and protocols
- To evaluate statistical parameters for later investigations.

3.4 Software

Microwave Studio Computer Simulation Technology (CST MWS) is a powerful tool for 3D electrical simulation of high gain frequency components. CST MWS allows for a rapid and precise assessment of HF systems such as filters, couplers, antennas, single and multi-layer constructions and SI and EMC impacts. CST MWS provides unprecedented performance, making it the first technology-leading choice in R&D departments. Exceptionally user-friendly, CST MWS gives the user a quick overview of high-frequency model EM conduct.

3.5 Design procedure

Step 1: First, based on the fundamental MPA design equations called the equation-based antenna, two rectangular microstrip patch antenna (MPA) components are designed to work in the 2.6 GHz and 28 GHz bands.

Step 2: Second, to find the right one based on the 5G criterion, distinct substrate material is used.

Step 3: Using various feeding methods to find the right one based on the 5G criteria now.

Step 4: For the design of 2.6 GHz and 28 GHz antennas, the best substrate material, best substrate height and best feeding technique were used.

Step 5: Save the structure and the antenna simulation.

Step 6: Save the outcome if the conditions are met by the antenna.

Step 7: For better performance, optimize the built-in Microstrip patch antenna.

Step 8: Using the 28 GHz band to split the slot with the required value.

Step 9: Save the structure and the antenna simulation.

Step 10: Save the outcome if the conditions are met by the antenna.

Step 11: Compare the outcome with the current antennas.

3.5.1 Antenna Design by Equation

The first step in the antenna design is to choose the right dielectric substrate with the appropriate thickness (h). Dieelectrics 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.

Some common dielectric substrates are listed in table 3.1 with their properties.

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

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

Patch width is given by,

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{3.1}$$

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

Effective dielectric constant is given by,

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

Where,

εeff= Effective dielectric constant,

εr= 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,

$$Leff = \frac{c}{2f_r\varepsilon_{eff}} \tag{3.3}$$

The actual length of the patch is given by,

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

where,

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

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

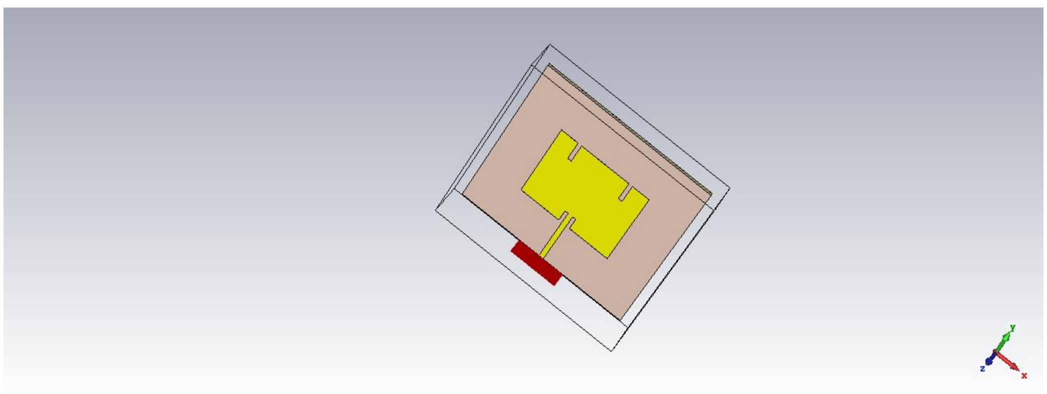

Figure 3.2 Equation based single element antenna

TABLE 3.2 Parameters of Single Element Antenna

Parameter	**Value**
Frequency (f)	2.6 GHz ; 28 GHz
Substrate height (h)	1.5 mm
Dielectric Constant, €r	2.2 mm
Patch Length (L)	38.13 mm
Patch Width (W)	45.58 mm

3.5.2 Optimization Through Optimizer in CST MWS

The optimization is applied to the geometric design by using an optimizer to increase the antenna gain once the single element antenna has been constructed using the formula. There are a number of algorithms for the optimizer to apply. Framework of the Like-Trust Area, Genetic Algorithm, Optimization of Particle Swarm and more. In this study, these "Trust Region Framework" algorithms are used as they produce better results and take less time. To achieve better antenna gain than the current single-element antennas, optimization is carried out several times.

TABLE 3. 3 Optimized Single Element Antenna Parameters

Parameter	**Value**
Frequency (f)	2.6 GHz ; 28 GHz
Substrate thickness (h)	1.791 mm
Dielectric Constant, $€_r$	2.2 mm
Length (L)	37.38729 mm
Width (W)	49.23529 mm

Chapter 4

Simulations and Result Analysis

This section is presents and analyzes the results attained after simulating the designed antenna.

4.1 Simulation Results of Single Element Antenna

4.1.1 Return Loss Graph

The return loss or S11 parameter is the most important things to test an antenna's output. Return loss gives important news related the reflected energy of an antenna. From the graph of S11 parameter vs frequency we can easily find out the operating frequency and bandwidth. The parameter value of S11 was decreased the higher the antenna's resonance. There are two frequency band are shown in below. One is lower frequency band and other is higher frequency band. In figure 4.1 is shown the S11 parameter of lower frequency band which operate at 2.6 GHz. And, the another figure 4.2 is shown the S11 parameter of higher frequency band which operate at 28 GHz. From this graph it is seen that the resonance frequency are 2.6 GHz and 28 GHz as it is optimized and the return loss value are about -23 dB and -16 dB.

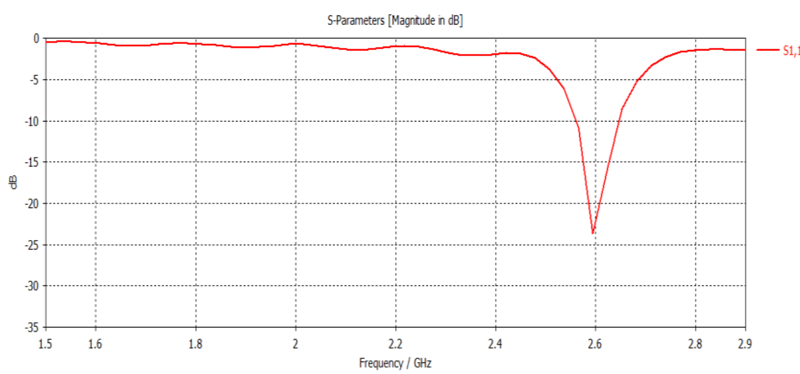

Figure 4.1 Equation-based single element antenna return loss plot for 2.6 GHz

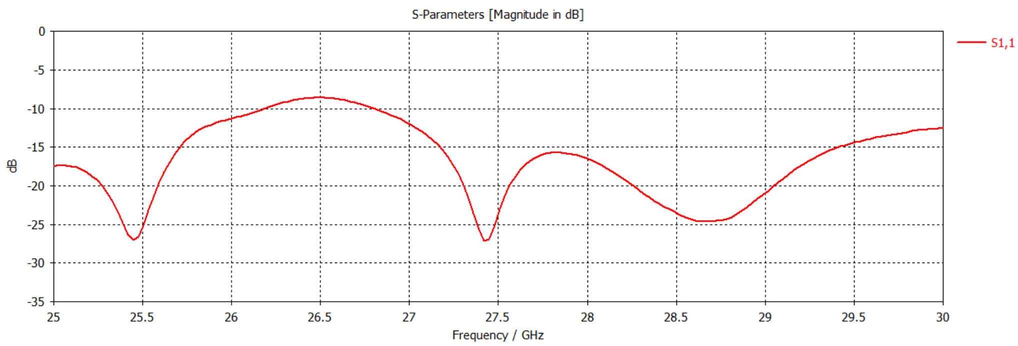

Figure 4.2 Equation-based single element antenna return loss plot for 28 GHz

4.1.2 Voltage Standing Wave Ratio (VSWR)

Yes, another one parameter is VSWR which is playing a vital rule because it's actually determines the antenna's impedance matching. It is a function of impedance matching loads to the characteristic impedance of a transmission line. Discriminations in impedance paraph to a standing wave along the transmission line and SWR is defined as the ratio of the partial standing wave amplitude to the amplitude of a node along the line. The default value for VSWR is 1 to 2. From the graph of the single element antenna below shows that the VSWR value is within the usual working frequency range 1 to 1.5.

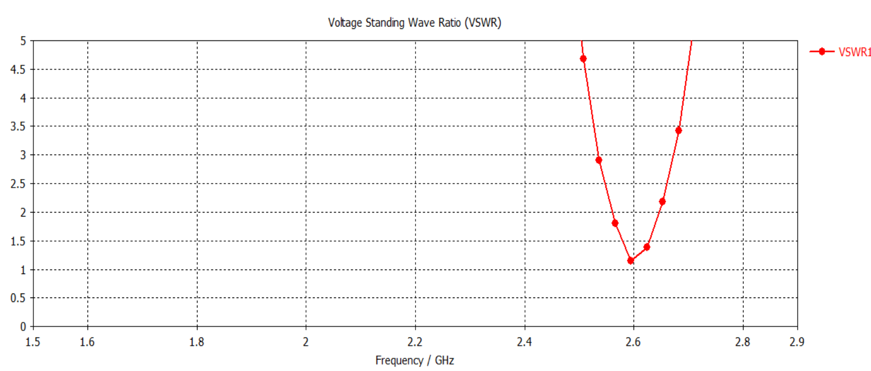

Figure 4.3 VSWR plot of equations based single element antenna for 2.6 GHz

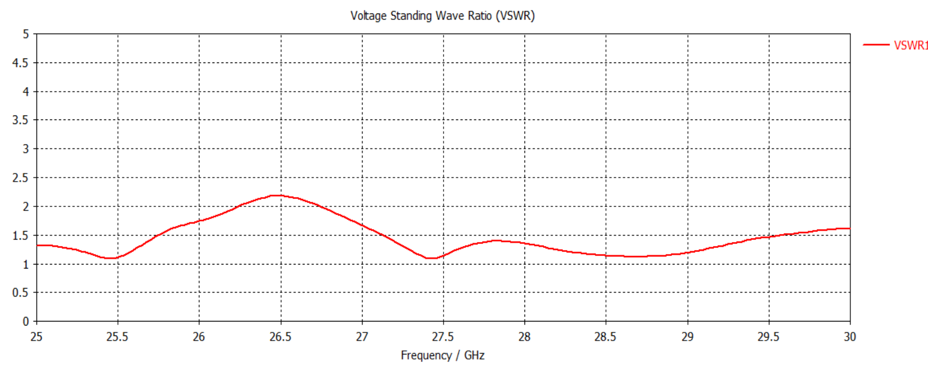

Figure 4.4 VSWR plot of equations based single element antenna for 28 GHz

4.1.3 2D Radiation Pattern

The term of radiation pattern is defined to the directional dependence on the antenna radio wave intensity for this field. Single element antenna 2D radiation pattern which a good radiation pattern and a limited beam width for the antenna being built. The pattern of radiation microstrip patch antenna is half circular and we see that our radiation pattern is perfectly match the standard which is nearly half circular.

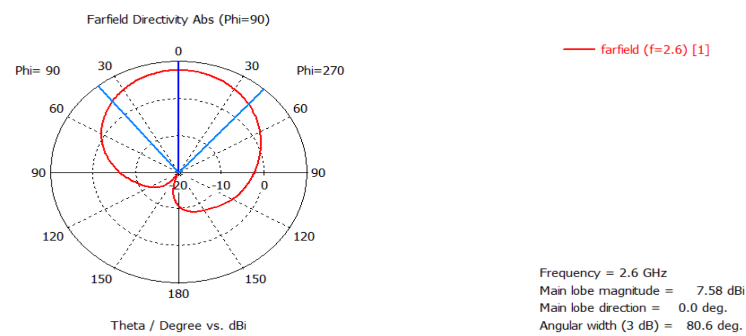

Figure 4.5 Single element antenna 2D radiation pattern for 2.6 GHz

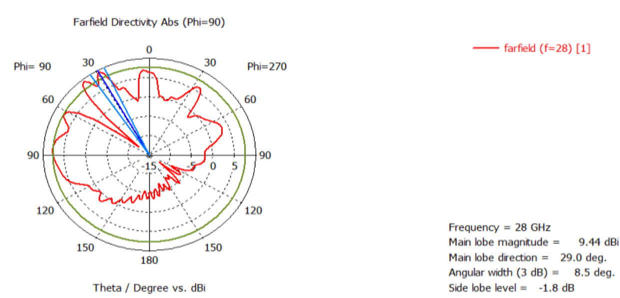

Figure 4.6 Single element antenna 2D radiation pattern for 28 GHz

4.1.4 3D Radiation Pattern

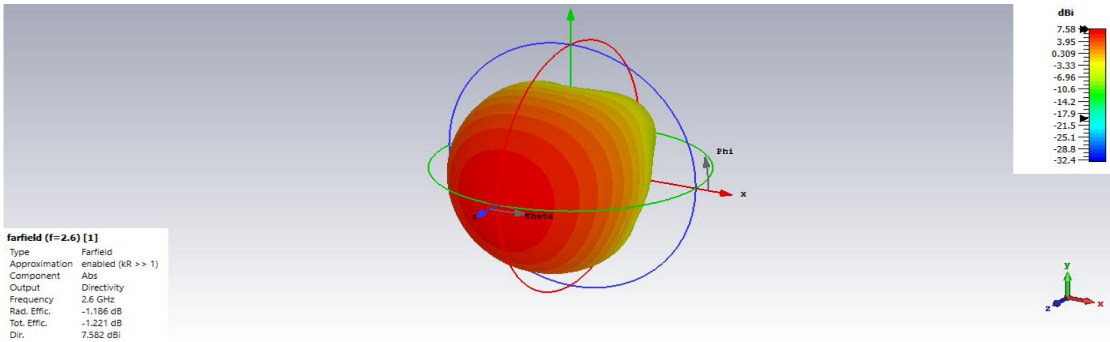

Figure 4.7 Single Element Antenna 3D Radiation Pattern at 2.6 GHz

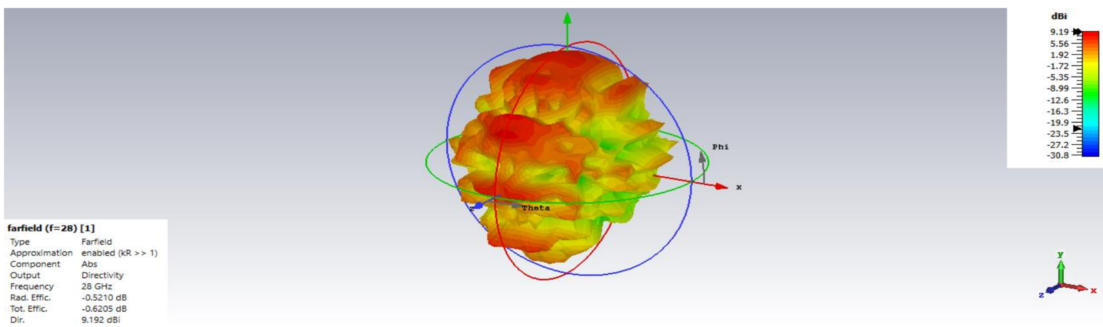

Figure 4.8 Single Element Antenna 3D Radiation Pattern at 28 GHz

An antenna which radiates energy in the surrounding space by the using of a 3D radiation pattern which show a 3-dimensional view. 3D Radiation pattern is known as the far-field which generally measured at a enough distance from the antenna. Simply, it is the energy radiated in a specific direction with mention to an isotropic antenna (a theoretical antenna that radiates equally in all the directions). It should be good antenna just like a 2D radiation pattern. Which operate the frequency range for it's 3D radiation pattern. For a certain direction it's very easy to observe delivered the energy from 3D radiation pattern. 3D radiation pattern is shown above at 2.6 GHz and 28 GHz.

4.1.5 Antenna Efficiency

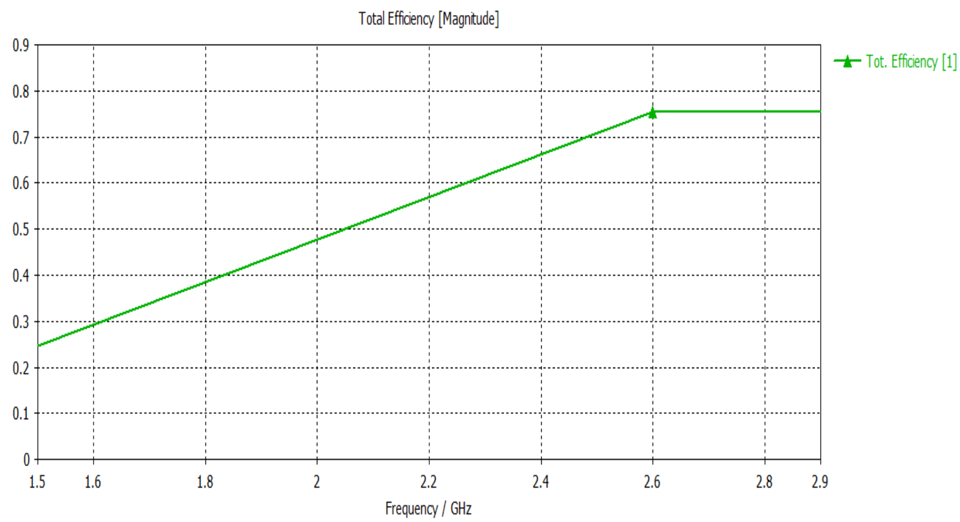

Figure 4.9 Antenna efficiency of single element antenna for 2.6 GHz

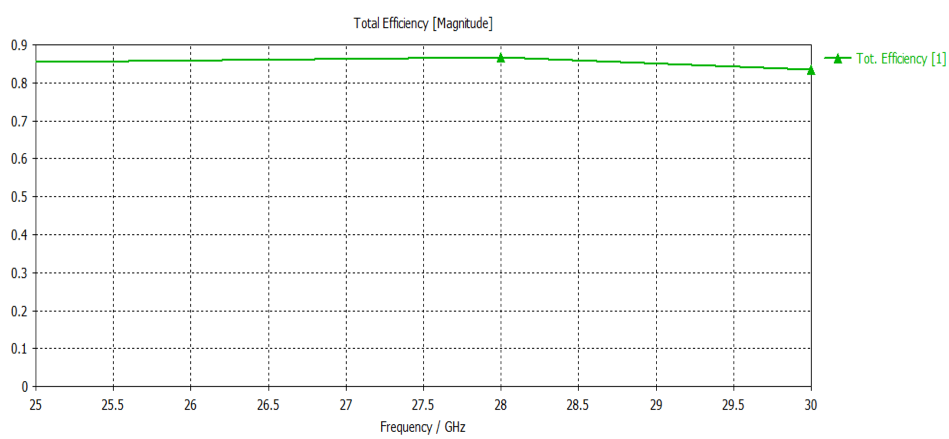

Figure 4.10 Antenna efficiency of single element antenna for 28 GHz

Generally, antenna effectiveness is defined between the relationship of the effective aperture area and it's actual physical area. The physical aperture area usually denoted by the percentage which defines the radio frequency (RF). Normally antenna performance of the standard value is 70 percent. Above figure 4.9 and 4.10 demonstrate that antenna efficiency is 75 percent for 2.6 GHz and 86 percent for 28 GHz.

4.1.6 Radiation Efficiency

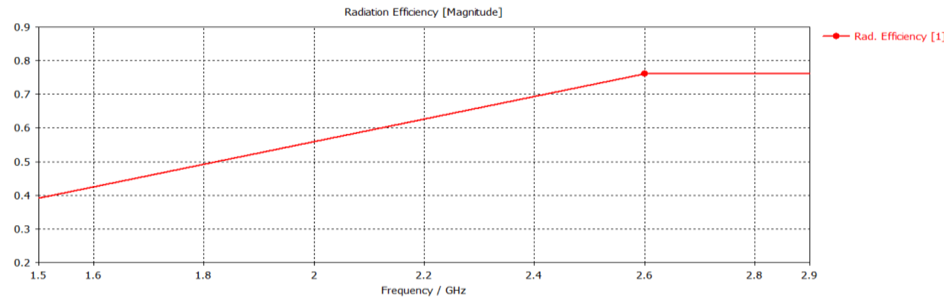

Figure 4.11 Radiation Efficiency of single element antenna for 2.6 GHz

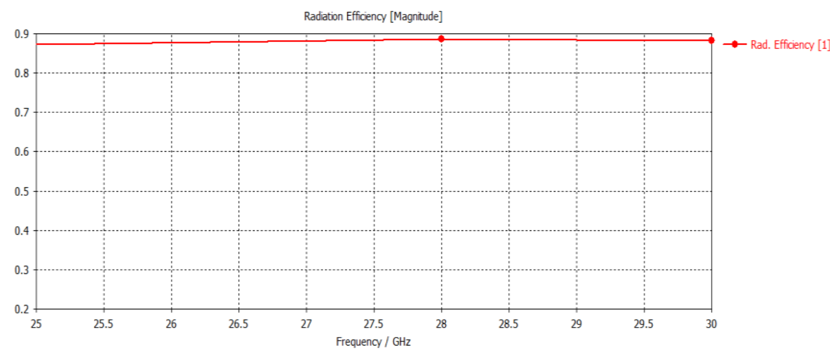

Figure 4.12 Radiation Efficiency of single element antenna for 28 GHz

The proportion of the radiated energy of the antenna which is defined by the radiation efficiency. To the free space to the electrical energy received by the antenna from the feedline. The standard level of radiation efficiency is 70 percent. From the figure 4.11 and 4.12 above seen that the radiation efficiency is 76 percent for 2.6 GHz and 88 percent for 28 GHz.

4.2 Final Design Result of Single Element

In table 4.1, full simulation results were displayed in tabular from after optimization of the single element antenna. This antenna design shows good loss of return value through GHz entire 2.6 GHz and 28 GHz band. In comparison, the antenna’s VSWR is below than 1.5. And gain also quite compared to the recent models of an antenna. Also this antenna directivity is almost 7.13dBi and 8.92dBi that is shows better directional performance. Gain 6.42 dBi at 2.6 GHz and 8.62 dBi at 28 GHz which are obtained by single element slot antenna. The antenna efficiency and radiation efficiency of this single component antenna reaches 70 and 90 percent throughout the whole band.

TABLE 4.1 Complete Simulation Result of Antenna Single Element

Parameters	**Value**	**Standard [10]**
Resonate Frequency	2.6 GHz ; 28 GHz	As per need
Bandwidth	85.8 MHz ; 3231 MHz	As per need
Return loss (S_{11})	-23 dB ; -16 dB	less than -10 dB
VSWR	1.14 ; 1.35	2 – 1
Gain	6.422 dBi ; 8.621 dBi	6-9 dBi
Directivity	7.13 dBi ; 8.92 dBi	5-8 dBi
Antenna Efficiency	75 % ; 86%	70%
Radiation Efficiency	76 % ; 88%	70%

4.3 Comparison with existing single element antennas

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

TABLE 4.2 Comparison with The Single Feature Antennas

Antenna ref.	**Year**	**Gain (dBi)**	**Bandwidth**	**Size (mm^3)**	**Efficiency**
[13]	2018	5 dBi 10 dBi	1.8- 3.1 GHz 27.2-28.5 GHz	100×60×0.76	60% 85%
[31]	2018	6.25 dBi 8.25 dBi	28 GHz 38 GHz	6×6×1.27	-
[32]	2018	6.32 dBi 7.54 dBi	3.3-3.6 GHz 4.8-5.0 GHz	15.5×7×0.8	(60-85)%
[33]	2018	-	(824-960) MHz (1710-2690) MHz (3300-3600) MHz (4800-5000) MHz	145×75×0.8	50% (75-90)%
[34]	2018	-	(3300-3600) MHz (4800-5000) MHz	130×74×0.8	50%
[37]	2018	10.9 dBi	28 GHz 38 GHz	53×20×0.203	85%
[39]	2017	(1-6.3) dBi	(2.5-6.5) GHz	33×33×0.8	(50-85)%
Proposed	2020	6.422 dBi 8.621 dBi	85.8 MHz 3231 MHz	91×80×1.5	(70-90)%

Chapter 5
Conclusion

In this thesis work we have try to design a multiband patch antenna for 5G wireless communication system by the cst software. Mainly two frequency band are used there such as 2.6 GHz and 28 GHz band. And the simulate optimized results slot antenna is compared with the recent designs by other researchers.

5.1 Achievements

This antenna is designed and simulated successfully with 50 ohm probe feed for a multiband patch antenna. The proposed antenna operate below -10dB return loss with the frequency at 2.6 GHz and 28 GHz. For the whole frequency band the VSWR of the simulated never less than 1 which maintain the standard value between 1 and 2. As declared by the Commission of Federal Communications (FCC) the whole band of 28 GHz which completely covers of the antenna bandwidth is around 2.5 GHz. Recently there are some high gain slot antennas are designed. But some of them do not cover the FCC and some of them are heavy size of mobile phone. So the proposed antenna it will be used by the powerfull candidate in future 5G mobile phones.

5.2 Limitations

The proposed antenna is somehow not approved with beam steering capabilities that will make this antenna more fruitful by using mobile phone.

5.3 Future Work Field

It is useful to add beam steering facility to improve the antenna coverage angle. In practically, the designed and simulated antenna should be used for the environment to see the actual function and also compare the simulation results with others measured.

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