BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

Design and Simulation of a Dual band Microstrip Patch Antenna for 5G Mobile Systems

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Dedication

This thesis is dedicated to all of my teachers and parents.

Certificate of Approval

The thesis titled as "**Design and Simulation of a Dual band Microstrip Patch Antenna for 5G Mobile Systems"** Submitted by **Md. Faisal Aziz, ID: T181017** to the International Islamic University Chittagong (IIUC) Department of Electronic and Telecommunication Engineering (ETE) has been found as satisfactory and accepted as partial fulfillment of the requirement for the B.Sc. in Electronic and Telecommunication Engineering on International Islamic University Chittagong**.**

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Candidates Declaration

The work described in this thesis has not been previously submitted for the granting of any degree or diploma, and it is hereby declared that it does not contain any statements that are illegal.

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Abstract

This research focuses on 5G mobile applications for high-band millimeter waves. The goal of the suggested microstrip patch antenna was to function at 28 and 38GHz, the first and most popular 5G frequency bands. In this work, a single rectangular patch, which is frequently used in other 5G antennas, is combined with a variety of two U slot shapes in order to improve the gain and other radiation properties of the antenna. Using CST Microwave Studio's electromagnetic simulation software, the suggested antenna has been built and investigated on a Rogers RT Duroid-5880 substrate with relative permittivity of 2.2. The designed antenna's gain, bandwidth, return loss, VSWR, and efficiency are 9.12 dBi, 700 MHz, -23.79 dB, 1.1, and 75% for 28 GHz, and 9.77 dBi, 950 MHz, -41.76 dB, 1.01, and 84% for 38 GHz respectively. The proposed antenna has a good chance of being used for 5G mmWave cellular communication.

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List of Symbols

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

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 Dimensions
2D	Two Dimensions
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
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System
FDMA	Frequency Division Multiple Access

Chapter 1

Introduction

Mobile Communication is the use of technology that allows us to communicate with others in different locations without the use of any physical connection (wires or cables). Mobile communication makes our life easier, and it saves time and effort.

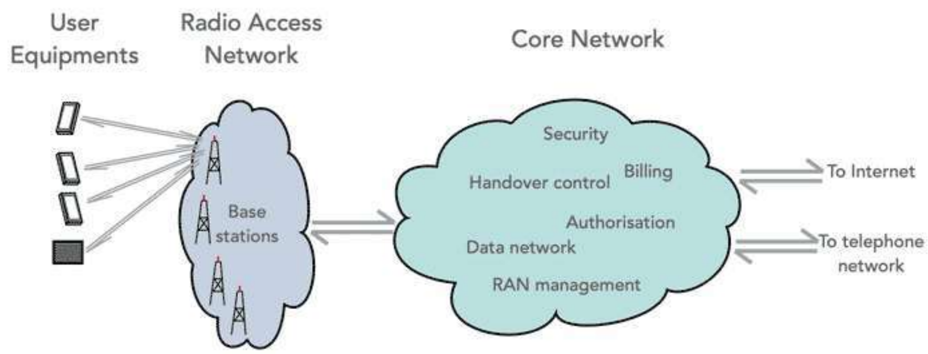


Figure 1.1 **:** Top level view of a mobile communications network

Since the early 1970s, the mobile wireless industry has been developing, revolutionizing, and evolving. The cellular communication sector has grown at a breakneck pace since the mid-nineties. When the cellular thought was initially actualized within the 1960s and 1970s, no one might have anticipated how far reaching remote communication networks would gotten to be. Mobile cellular subscriptions are growing at a rate of 40% per year, and by the end of 2010, there will be four times as many as conventional telephone lines. The fast increase of cellular telephone customers throughout the world has shown beyond a shadow of a doubt that wireless communications is a reliable and viable voice and data delivery system. Because of cellular widespread popularity, other wireless systems and standards have been developed for a variety of different forms of telecommunication traffic in addition to mobile voice telephone calls.

1.1 Evolution of Mobile Communication

Communication is changing quickly among generations, from generation Zero to generation Five. Cellular networks and technology have advanced meaningfully since their introduction in the late 1970s, with subsequent generations (2G through 4G) marking key signs in the evolution of mobile communication. Each network generation marked an important landmark in the evolution of mobile data communications.

Figure 1.2 Evolution of communication

1.2 Zero Generation Technology (0G)

Wireless phone begun with 0G, which might have called Zero Generation, became accessible after the World War-II. The calls were set up by cell providers because there were few open communication channels at the time. These mobile devices might not be able to support the handover means feature. alter the channel's frequency while 0G 1G 2G 3G 4G 5G moving. The term "zero generation" describes the early 1970s pre-cellular mobile system. Before cell phones were invented,, some subscribers had radio telephones in their vehicles. Modern cellular mobile-telephone technology was created by the mobile radio telephony system. These systems are referred to as 0G (Zero Era) Systems. Given that they were first generation cell phones' origin. Technologies used in Zero Generation systems included Mobile Telephone System (MTS), Public Land Mobile Telephony (PLT) , Improved Mobile Telephone Service (IMTS), Advanced Mobile Telephone System (AMTS), Norwegian Offending Land-Mobile Telephone (OLT), and Swedish Mobile Telephony System D (MTD) and Push to Talk (PTT). Loggers, project managers, real estate agents, and famous people all used the system. Using just voice communication, the communication system was employed. [29]

1.3 First Generation Technology (1G)

First Generation mobile networks first appeared in Japan, the year in 1979, though they were not termed 1G at the time, and then spread to other countries such as the United States in 1980 and the United Kingdom in 198 (1985). 1G network had such a channel capacity of 30 KHz and a speed of 2.4kbps. Frequency Division Multiple Access (FDMA) modulation was used in an analog technology known as the Advanced Mobile Phone System (AMPS). On 1G networks, only voice communication was possible due to reliability issues, signal interference issues, and insufficient hacker protection. 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).

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)
- Method of service : voice only
- Access technique: Frequency Division Multiple Access (FDMA)

Limitations of 1G system

Limitations of the 1G system as shown below:

- Poor interference results in voice quality
- A low battery life
- Large mobile phone size (not convenient to carry)

- Reduced safety (calls could be decoded using an FM demodulator)
- Limited user base and cell coverage
- Moving between similar systems was impossible

1.4 Second Generation Technology (2G)

2G or Second-Generation wireless network was developed using early 1990 digital technologies. In Finland, 2G was launched in 1991. The 1st Generation network was not perfect, but it kept going until 1991 when it was supplanted by the 2G arrange. Even though the First Generation network wasn't ideal, it lasted until 1991, when the Second Generation network took its place. The capacity and security of this underutilized, flexible network were greatly improved by using computerized signals rather than simple ones. Clients could send SMS and MMS messages at modest rates of up to 64 kbps using 2G systems, which had transfer speeds ranging from 30 to 200 kHz. With the introduction of 2.5G, which included package exchange in the form of GPRS and EDGE, GSM technology continued to advance. And after the introduction of GPRS in 1997, customers could send and receive emails while traveling. For the past 20 years, this technology has undergone constant development in order to provide improved services. On the basis of the original GSM, various new technologies that are common in some reduction systems known as 2.5 generation (2.5 G) systems have been created. [28].

Features of 2G system:

Key features of the 1G system as shown below-

- Digital system (switching)
- Possibility of SMS services
- The ability to roam
- Increased security
- Lower data rates on the first internet
- Drawbacks of the 2G system
- Low data rate
- Limited user base and hardware capabilities

Limitations of 2G system :

- Low data transmission rate
- Partial mobility
- Fewer features on mobile devices

1.5 Third Generation Technology (3G)

The third generation of wireless communication standards is defined by the Telecommunication Standards Group (3GThe major objective of 3G, which was moreover based on GSM, was to supply high-speed information, with the initial 3G innovation permitting information speeds of up to 14Mbps. Clients may conduct video discussions, get to the net, trade records, play online recreations, and indeed observe TV online much appreciated to 3G's capacity to transport bigger sums of information at quicker rates. Whereas 2G networks could download a 3-minute MP3 music in 6-9 minutes, 3G networks would take anything from 11 to 90 seconds to download the same file.

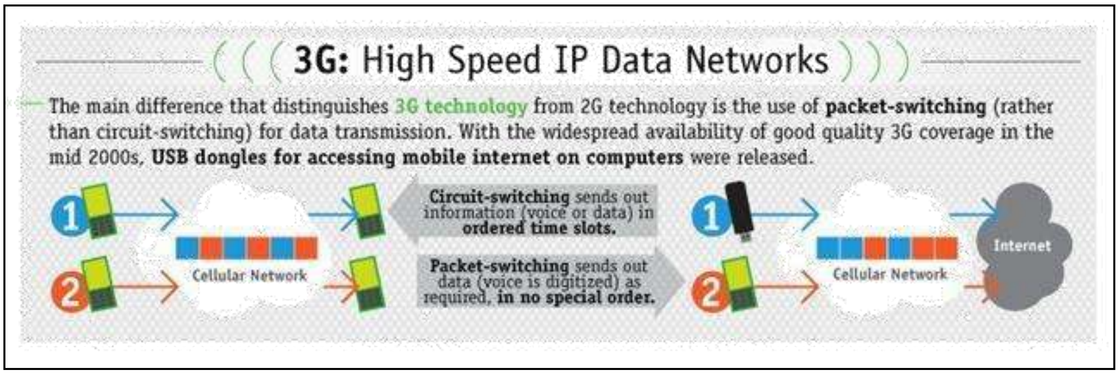


Figure 1.3   3G vs. 2G Communications [27]

With the use of 3G technology, network operators are able to provide their users with a wider range of more advanced amenities by improving network capacity and Spectral Efficiency. Wide-area wireless phone calls, video calls, mobile television, wireless broadband data, GPS service, and video conferencing are all included in the 3G system services, which are all provided in a portable wireless environment.

Features of 3G system

Key features of 3G system is given below -

- better data rate
- calling a video
- increased users, coverage, and improved security
- support for mobile apps
- support for multimedia messages
- Maps and location tracking
- A better web experience
- streaming TV
- Superior 3D games

Limitations of 3G systems:

Limitations of G system are written below:

- Expensive spectrum licenses
- Expensive implementation, equipment, and infrastructure
- Higher bandwidth requirements to support higher data rate
- Costly mobile devices
- Compatibility with frequency bands and older 2G systems [26]

1.6 Fourth Generation Technology (4G):

4G is the fourth generation of broadband cellular network technology, succeeding 3G and preceding 5G. The introduction of 4G marked the beginning of the era of the smart phone and portable multipurpose device. 4G is the primary era to utilize Long-Term Evolution (LTE) innovation to attain potential download rates of 10Mbps to 1Gbps, giving conclusion clients with lower inactivity (less buffering), improved voice quality, moment informing and social organizing, high-quality gushing, and quicker download rates. The innovation is being created to oblige the Quality of Benefit (QoS) and rate prerequisites required by applications such as remote broadband get to, Multimedia Messaging Service (MMS), video chat, and others. 4G is additionally the primary IP-based versatile arrange, taking care of voice as fair another benefit. Clients may appreciate lower inactivity (less buffering), more prominent call quality, and fast get to to moment informing and social media, high-quality spilling.

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 1.4 4G cell phone generation compared [27]

Features of 4G systems:

Features 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

Limitations of 4G system:

Limitations 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 [26].

1.7 Fifth Generation Technology (5G)

5G is the 5th generation mobile network. 5G wireless technology is a promising solution for multi-Gbps data rates in future mobile communications. It is a new global wireless standard after 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices. It is Up to 100 times faster than 4G, 5G is creating never-before-seen opportunities for people and businesses. Faster connectivity speeds, ultra-low latency and greater bandwidth is advancing societies, transforming industries and dramatically enhancing day-to-day experiences. Services that we used to see as futuristic, such as e-health, connected vehicles and traffic systems and advanced mobile cloud gaming have arrived. 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.

Features of 5G :

Features of 5G is given below :

- 1-10Gbps connectivity to field end points
- 1 ms of latencies
- A bandwidth per area of 10x to 100x
- 10 to 100 times as many connected devices

- 99.999 percent availability
- Complete coverage
- 90% reduction in system energy use [26]

Global 5G spectrum update :

Around the world, these bands have been allocated or targeted

Figure 1.5 : Global 5G spectrum

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

Licensed Spectrum

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

1.9 Antenna Basics

An antenna is a device that is made out of a conductive, metallic material and has the purpose of transmitting and/or receiving electromagnetic waves, usually radio wave signals. It is a dedicated transducer which transforms radio-frequency (RF) fields into electrical energy or vice-versa. There are two fundamental kinds: the receiving antenna, which collects RF energy and sends alternating current to the device, and the transmitting antenna, which receives electrical energy from the apparatus and generates radio-frequency field. Microstrip patch antennas are the most common type of antenna used in wireless applications , which is utilized for wireless communications. Typically, only microwave frequencies are appropriate for using microstrip patch antennas.

Frequency

Frequency describes the number of waves that pass a fixed place in a given amount of time. Antenna Frequency is defined as the number of cycles of a wave per second. 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.

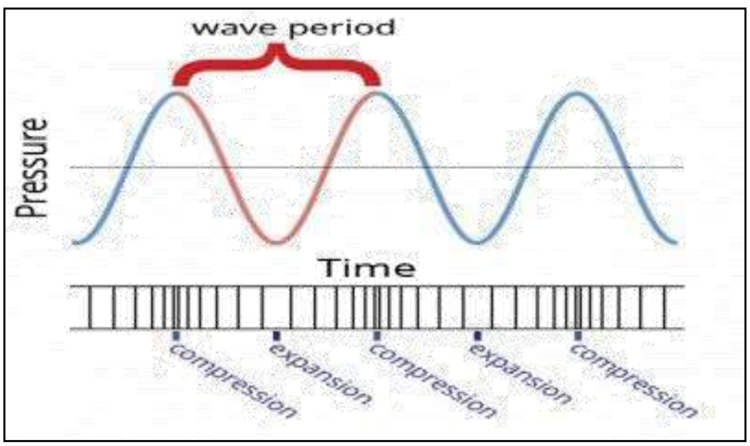
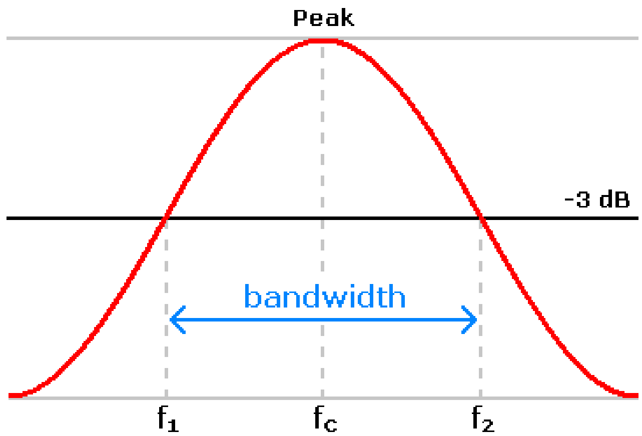


Figure 1.6. Frequency diagram

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 a certain amount of time from one point to another across a computer network or internet connection, typically in one second. Considering antenna, the term "bandwidth" describes the range of frequencies that an antenna can effectively transmit or receive energy over. Generally, one of the most important factors required to select an antenna is Bandwidth.



hs.

Figure 1.7 Bandwidth diagram

Impedance Matching

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. Impedance matching between the antenna and the circuitry is required for wireless transmission. Tuning or matching the antenna is the process of adjusting the impedance of the antenna, the transmission line, and the electronics throughout a frequency range, according to the theory of Maximum Power Transfer. VSWR is a measurement of the match's quality, and bandwidth is the range of frequencies where the antenna impedance is close to 50 Ohms for a particular VSWR.

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 100watt 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.

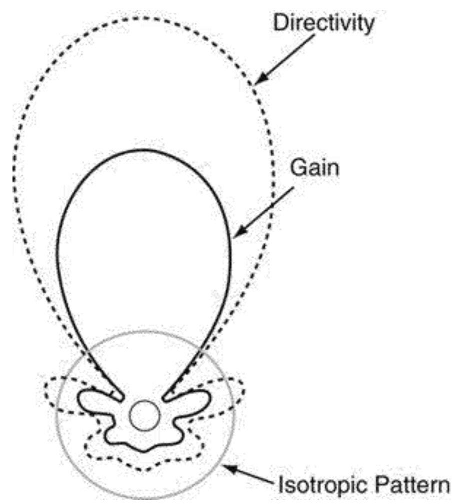


Figure 1.8: Directivity and Gain

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 1.8

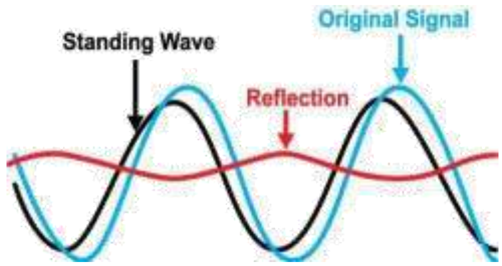


Figure 1.9 VSWR

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 feed line 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 = 0dB, 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 [30].

1.10 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 1.9. 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.

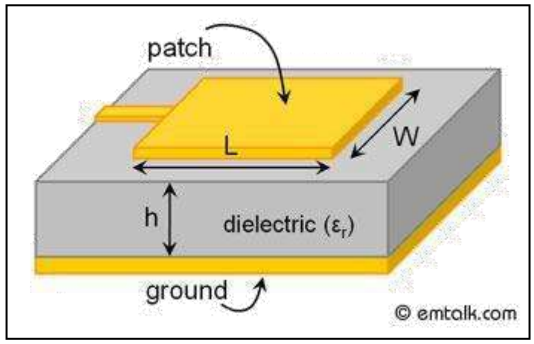


Figure 1.10 A Microstrip Patch Antenna Arrangement [31]

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 5007 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.

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 .
6. They're capable of dual and triple frequency operations.

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. Their capacity for handling power is low.

1.11 Design Tool

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.

1.12 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.

Chapter 2

Literature Review

2.1 Requirements of 5G

In arrange to guarantee that the proper 5G remote framework is developed, it is fundamental to gather and concur the necessities of the framework. By collecting the prerequisites, it is conceivable to get the wants and design the 5G remote framework to meet the prerequisites, and in that way satisfy wants. By concurring the prerequisites, all parties can work towards developing the same framework and create work-arounds where them, It possess specific needs may not be sufficiently met. Care should be taken that the 5G prerequisites are carefully collected and examined so that the most excellent framework is accomplished. Something else it seems result in a framework that's not usable.

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

2.2 Paper Review

The work of other researchers related to this thesis "Design and Simulation of a Dual Band Microstrip Patch Antenna for 5G Mobile Applications" 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] **Small Form Factor Dual Band (28/38 GHz) PIFA Antenna for 5G Applications**

This paper presents for the first time, the design of a dual band PIFA antenna for 5G applications on a low-cost substrate with smallest form factor and widest bandwidth in both bands (28 GHz and 38 GHz). The proposed dual band PIFA antenna consists of a shorted patch and a modified U-shaped slot in the patch. The antenna shows good matching at and around both center frequencies. The antenna shows clean radiation pattern and bandwidth of 3.34 GHz and 1.395 GHz and gain of 3.75 dBi and 5.06 dBi at 28 and 38 GHz respectively.[1]

[2] **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 .[2]

[3] **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 .[3]

[4] **Design and Analysis of Millimeter Wave Dielectric Resonator Antenna for 5G Wireless Communication Systems**

This work presents a novel multiband rectangular dielectric resonator antenna for future 5G wireless communication system, having stacked radiator with semi-circular slots etched on the left and right sides of an upper radiator. Additionally, a semi-elliptical slots rectangular microstrip patch antenna of the same dimensions for the purpose of comparison is designed. 28 and 38 GHz, which are the proposed 5G bands by most researchers, are the core target of this work. On the other hand, the proposed microstrip antenna resonates at 28 and 38GHz with a 1.49 and 1.01GHz of moderate impedance bandwidth, having −23.6 and −27.1 dB of satisfactory return loss. Further, the proposed patch antenna has a maximum radiation efficiency of 90.33% at 28 GHz, with overall radiation efficiency of greater than 84%, and moderate gain of 5.45 dBi is also noted.[4]

[5] **28/38 GHz Dual-band Dual-polarized Highly Isolated Antenna for 5G Phased Array Applications**

This paper proposed a new dual-band dual-polarized array antenna operating at 28 GHz and 38 GHz for 5G communication applications. Three stacked patches are adopted to achieve the dual-band operation. The lower band from 27.48 to 28.50 GHz is achieved by using the lower large patch, which is couple-fed by the middle patch. For the antenna element, the simulated -12 dB bandwidths are 27.48-28.50 GHz and 36.94-40.43 GHz for the two bands, respectively. The in-band gains are over 6 dBi in the lower band, and over 4 dBi in the upper band. For the 2×2 antenna array, the isolations are better than 20 dB in both band. [5]

[6] **Novel Dual-Band 28/38 GHz MIMO Antennas for 5G Mobile Applications**

This paper introduces new compact microstrip line fed dual-band printed MIMO antennas resonating at 28 GHz and 38 GHz which are appropriate for 5G mobile communications. The dual-band response is attained from inverted I-shaped slots inserted in main patches. The substrate size is 55×110mm2, while the introduced antennas have very modest planar configurations and inhabit an insignificant area which make them fit easier within handset devices for the forthcoming 5G mobile communications. Better return losses and larger bandwidths are realized. [6]

[7] **A Single Band Antenna Design for Future Millimeter Wave Wireless Communication at 38 GHz**

In this paper, they proposed an antenna, which is suitable for the millimeter wave frequency. The single band antenna consists of new slot loaded on the radiating patch with the 50 ohms microstrip line feeding used. This single band antenna was simulated on a FR4 dielectric substrate have relative permittivity 4.4, loss tangent 0.02, and height 1.6 mm. The antenna was simulated by Electromagnetic simulation, computer software technology High Frequency Structural Simulator. And simulated result on return loss, VSWR, radiation pattern and 3D gain was presented.[7]

[8] **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 .[8]

[9] **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 .[9]

[10] **Compact Planar Four-port MIMO Antenna for 28/38 GHz Millimeter-wave 5G Applications**

This article presents a planar four-port microstrip line-fed Multiple-Input Multiple-Output (MIMO) antenna operating at 5G millimeter-wave candidate bands of 28 GHz and 38 GHz. A rectangular shaped patch antenna is designed as a main radiator to obtain a resonance at 28 GHz. Etching of a single element split-ring resonator (SRR) metamaterial unit cell from the basic patch radiator introduces an additional resonance band at 38 GHz. The investigated diversity performance parameters, which result in an envelope correlation coefficient below 0.005, diversity gain of almost 10 dB, and channel capacity loss of less than 0.35 bits/s/Hz, are all found within their conventional limits. The findings show the viability of the design for millimeter-wave 5G applications.[10]

[11] **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 .[11]

[12] **5G mm-wave Antenna Array Based on T-slot Antenna for 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 .[12]

[13] **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.[13]

[14] **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 .[14]

[15] **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 .[15]

[16] **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% .[16]

[17] **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 .[17]

[18] **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. 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.[18]

[19] A Small Dual Band (28/38 GHz) Elliptical Antenna For 5G Applications With DGS

In this paper, a compact elliptical dual-band microstrip antenna fed with a coplanar waveguide is presented. The proposed antenna is designed and analyzed using a 3-D full-wave electromagnetic software named, High Frequency Structure Simulator (HFSS) software based on finite element method (FEM). The design adopts a bi-layer substrate configuration where the elliptical radiating patch is printed on a Rogers RO3010 substrate of dimensions 2.265x2x0.75mm3, with a dielectric constant of 10.2 and loss tangent of 3.5.10-3 at 9.4 GHz on which the radiating patch occupies a surface area of 0.754mm2. Moreover, Rogers RO3010 is placed on the top of another dielectric, which is a Rogers RO4350B, having a relative permittivity constant of 3.66 and loss tangent of 4.10-3 at 9.4 GHz. The antenna operates at 28GHz and 38GHz, two of the selected bands allocated to 5G by International Telecommunications Union. The simulation results show that the antenna achieves a minimum wide bandwidth of 4.14GHz and a constant gain of 6dB over the operating frequency range.[19]

[20] Dual-Band 28/38 GHz Inverted-F Array Antenna for Fifth Generation Mobile Applications

In this article, a new 28/38 GHz dual-band “inverted-F” array antenna for 5G applications is proposed. This antenna can be integrated in OLEDs (Organic Light Emitting Diodes) panels which can be used both for lighting or display. This 5G antenna, composed of 32 elements, has the advantage of a dual-band and compact structure. Each element of the array antenna has the shape of an “inverted-F” antenna. This array antenna can cover the 28 GHz band (27.94–28.83 GHz) and the 38 GHz band (37.97–38.96 GHz) with mutual coupling between the elements less than 35 dB.[20]

[21] **Dual-Band 28/38 GHz Coupled Quarter-Mode Substrate Integrated Waveguide Antenna Array for Next-Generation Wireless Systems**

A novel dual-band substrate integrated waveguide (SIW) antenna array topology is proposed for operation in the 28 GHz and 38 GHz frequency bands. The computer-aided design process yields a four-element antenna array that entirely covers the 28 GHz band (27.5 – 29.5 GHz) and 38 GHz band (37.0 – 38.6 GHz) with a measured impedance bandwidth of 3.65 GHz and 2.19 GHz, respectively. A measured broadside gain of 10.1 dBi, a radiation efficiency of 75.75 % and a 3 dB beamwidth of 25° are achieved in the 28 GHz band. Moreover, in the 38 GHz band the measured broadside gain amounts to 10.2 dBi, a radiation efficiency of 70.65 % is achieved and the 3 dB beamwidth is 20°.[21]

[22] **5G dual-band slotted SIW array antenna 2019**

A dual-band slotted substrate-integrated waveguide four-element array antenna for the 5G communication system is presented in this manuscript. Two longitudinal slots are responsible for generating frequency bands of 28 and 38 GHz. The proposed antenna is designed on the substrate duroid 5880/Rogers having a loss tangent and dielectric constant of 0.003 and 2.2, respectively. The developed single-element design at 28 GHz provides 6.35 dBi gain, while at 38 GHz it provides 7.3 dBi gain and the simulation is carried out with CST Microwave Studio, 2018. The designed antenna array attains the radiation efficiency of 88.08% with 12.7 dBi gain at 28 GHz and the efficiency of 84.44% with 15.5 dBi gain at 38 GHz band.[22]

[23] **Design of 28/38 GHz Dual-Band SIW Slot antenna for 5G Applications**

This paper shows a dual-band linearly polarized substrate integrated waveguide (SIW) antenna with two slots on the substrate for future 5G communication networks. The proposed antenna structure is resonating at 28 GHz and 38 GHz frequency bands,which are suitable for 5G mobile communications. The presented SIW antenna is designed on low loss Rogers RT/duroid 5880 substrate with dielectric constant r of 2.2 and loss tangent tan of 0.003. The antenna shows the bandwidth of 0.99 GHz and 0.40 GHz at 28 and 38 GHz separately. The acquired directive gain and efficiency of the proposed designfor 28 GHz is 7.2dBi and 93.28% respectively, and for 38 GHz the directive gain is 11.2dBi and efficiency is 85.68%.[23]

[24] **Dual-band Planar Spiral Monopole Antenna for 28/38 GHz Frequency Bands**

This paper presents a dual-band spiral planar monopole antenna working in 5G candidate bands of 28 and 38 GHz. Structure of the proposed antenna is a spiral that has two arms, each one responsible for a different resonant frequency. The antenna has a peak gain of 4.73 dBi and efficiency greater than 90% in both bands. The proposed antenna has a size of 4×8 mm2. A very high gain of 12.7 dBi is obtained when the antenna is used in an 8-element array configuration. The overall antenna array has a size of 8×48 mm2. The radiation patterns exhibit a very narrow beam-width of as narrow as 8 degrees. The high gain and small size makes this antenna suitable for future 5G mobile phones.[24]

[25] **28/38 GHz Dual-Band Microstrip Patch Antenna with DGS and Stub-Slot Configurations and Its 2x2 MIMO Antenna Design for 5G Wireless Communication**

This paper proposed a dual-band microstrip patch antenna with a wide bandwidth that works for 28 GHz and 38 GHz frequency bands. Defected Ground Structure (DGS) and stub slot configuration have been used to achieve wide bandwidth and dual-band, the overall size of the antenna is 8.25 x 9.69x0.45 mm3. The proposed antenna exhibits a -10-dB impedance bandwidth of 5.13 GHz and 11.63 GHz, gain of 8.31 dB and 6.38 dB and 98% efficiency for both 28 and 38.5 GHz resonant frequency respectively. A 2x2 MIMO antenna also designed where isolation is less than -20 dB between different ports.[25]

2.2 Summary

Several studies have been conducted on the construction of dual band patch antennas using slot antenna for various bands. The current research makes it clear that the various millimeter wave bands are the most prospective and significant choice for 5G wireless communication, as a lot of research has been done that covers those frequency bands. Again, designing a high-gain slot antenna to overcome high signal loss while being sufficiently small to complying with the new and be simpler to produce into a mobile phone is the most challenging task in 5G deployment.

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 5G.
- Study on antenna requirements for 5G.
- Study literature on slot based microstrip patch antenna and existing 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.

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. Although 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 multilayer 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 Objectives

- To design and simulate dual band patch antenna for future 5G mobile systems for 28 GHz and 38 GHz.
- To improve performance of parameters from existing antenna 5G mobile systems in comparison to latest literatures.
- To simulate the designed antenna in CST.

3.6 Design procedure :

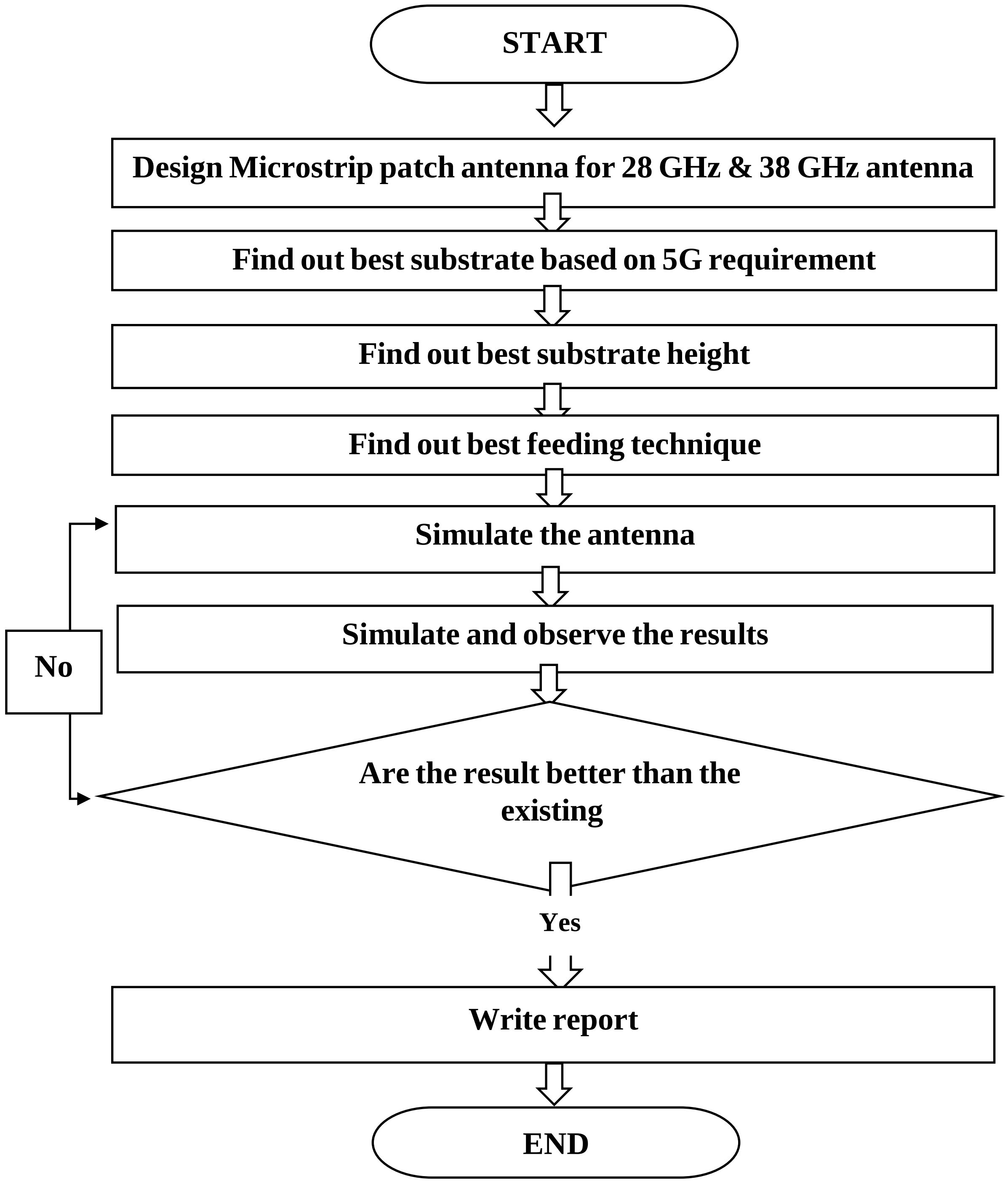


Figure 3.1 Design Flow Chart of Proposed Antenna

3.7Antenna Design Equation

The first step in the antenna design is to select the right dielectric substrate with the appropriate thickness (h). Dielectrics are used for electrical and mechanical stability changes. They are used to reduce the size of the antenna and help generate displacement current, which in the Magnetic Field (Ampere's Law) in turn generates varying time. In turn, this time varying Magnetic Field will generate time varying Electric Field (by the law of Faraday) and an electromagnetic propagating field is formed. In this way, the substrate can improve the radiation capability of the antenna.

The dielectric constants of the substrates of the table above are comparatively high, which indicate high loss for designing antenna with elevated benefit. The Rogers RT Duroid 5880 material with a dielectric constant close to 2.2 is selected for this design because the purpose of this study is to design a multiband patch antenna. Then it is appropriate to pick the material on the microstrip line and the field. We have three options in this case: Copper, Silver or Gold. The conductivity of silver is higher than that of the other metals. 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 (3.1 –3.5) 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,

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

Where,

εeff= Effective dielectric constant,

ε_r= 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,

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

3.8 Basic Antenna Design

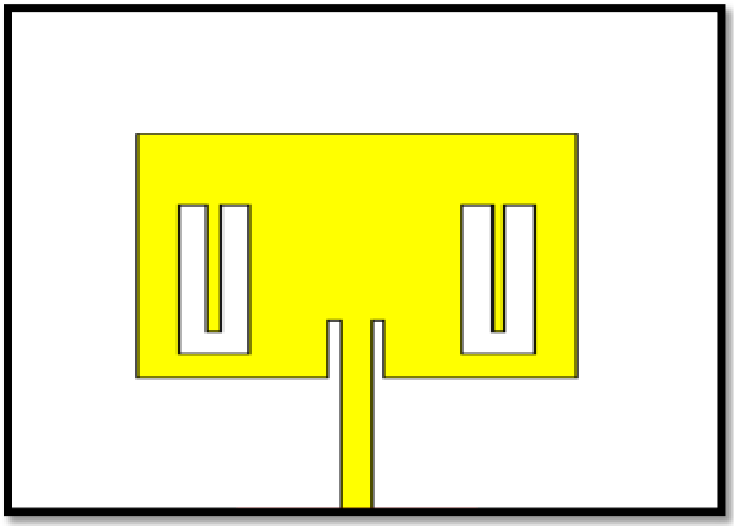


Fig 3.2 View of single element antenna

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

TABLE 3.2 Parameters of Single Element Antenna

Parameter	Parameter Value
Frequency (f)	28 GHz ; 38 GHz
Substrate height (h)	.508 mm
Dielectric Constant, €r	2.2
Patch Length (lp)	9.7 mm
Patch Width (wp)	9.9 mm
Ground Thickness(hg)	0.035 mm
Feed Width (wf)	0.7 mm
Cut Length (lc)	2.3 mm
Cut Width (wc)	1.6 mm

3.9 Slot Antenna Design

A dual band u shape slot antenna is designed to meet the purpose of our research, which is to design a high gain antenna. A slot antenna is a flexible antenna with asmall slit in the ground plane.It has been used in several wireless and radar applications and can be fed by waveguide, co planar waveguide (CPW), coaxial, slot line, or microstrip with some changes. The slot canal so be cavity-or reflector-backed to prevent back side radiation, adding weight and complexity.

The proposed antenna was designed on a Rogers RT5880 substrate with a dielectric constant of 2.2, and loss tangent of 0.0009. The top surface of the radiating patch consists of two U slots. We cut our two U-shaped slots on either end of the antenna patch. One is on the far right side of the patch and the other is on the left side of the patch, which has feed in the middle. Two slots over the radiating patch have been adapted to resonate with the antenna at frequencies 28 & 38 GHz.

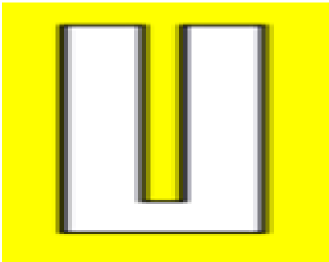


Figure 3.3 Slot Antenna Design

Table 3.3 Two slots parameter

Parameter	Parameter Value
Frequency	28 & 38 GHz
Slot Length (ls)	5.90 mm
Slot Width(ws) (1)	1.60 mm
Slot Width(ws) (2)	.65 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

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 and higher frequency bands which operates at 28 And 38 GHz. From this graph it is seen that the resonance frequency are 28 GHz and 38 GHz. The return loss value are about -23.79 dB and -41.76 dB.

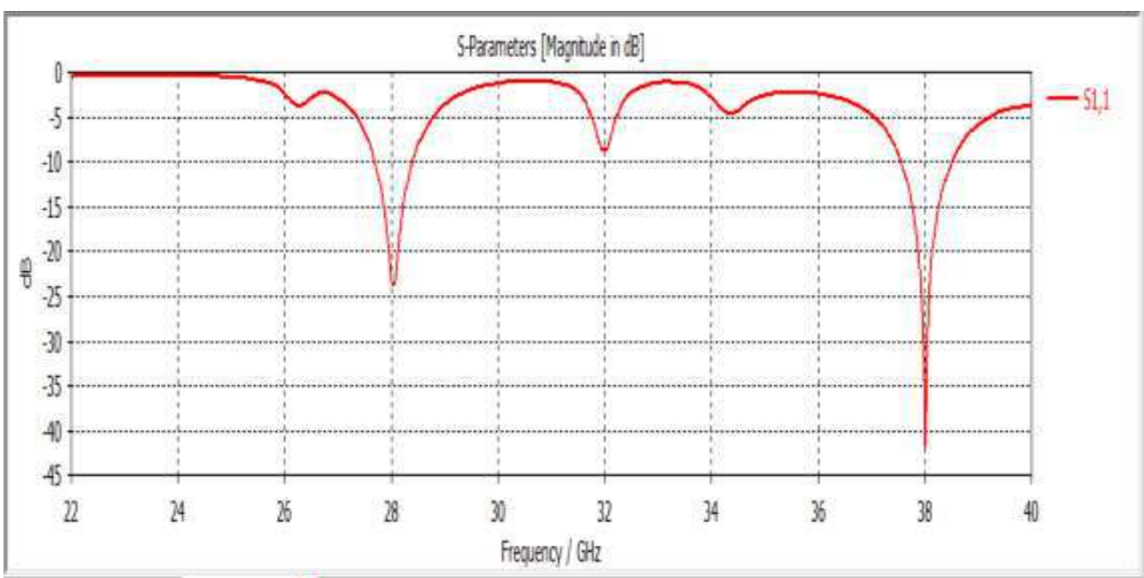


Figure 4.1 Equation-based single element antenna return loss plot for 28 & 38 GHz

Voltage Standing Wave Ratio (VSWR)

Another 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 VSWR 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.

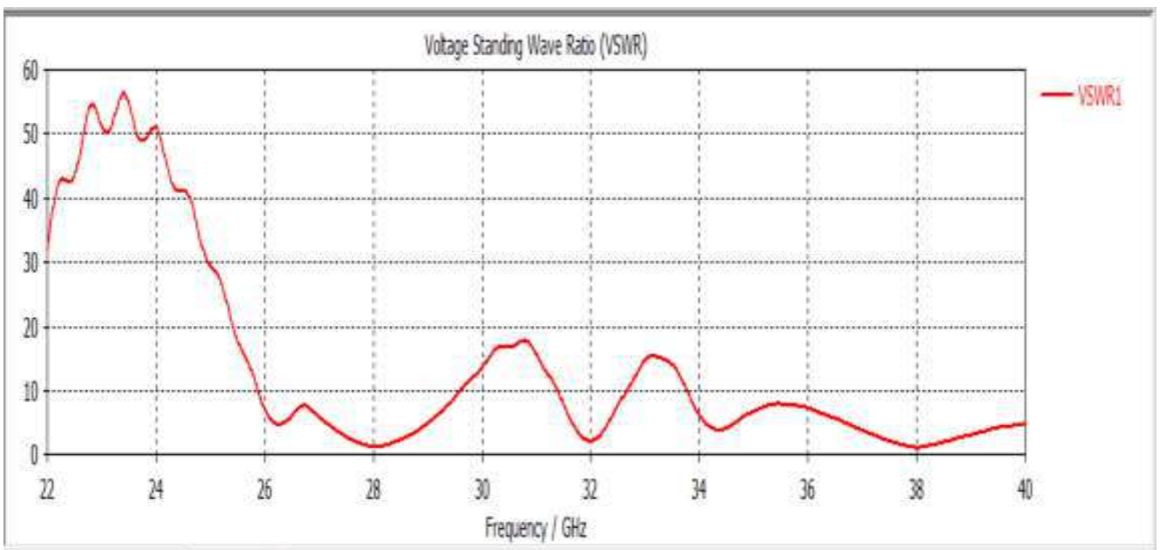


Figure 4.2 VSWR plot of equations based single element antenna for 28 and 38 GHz

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.

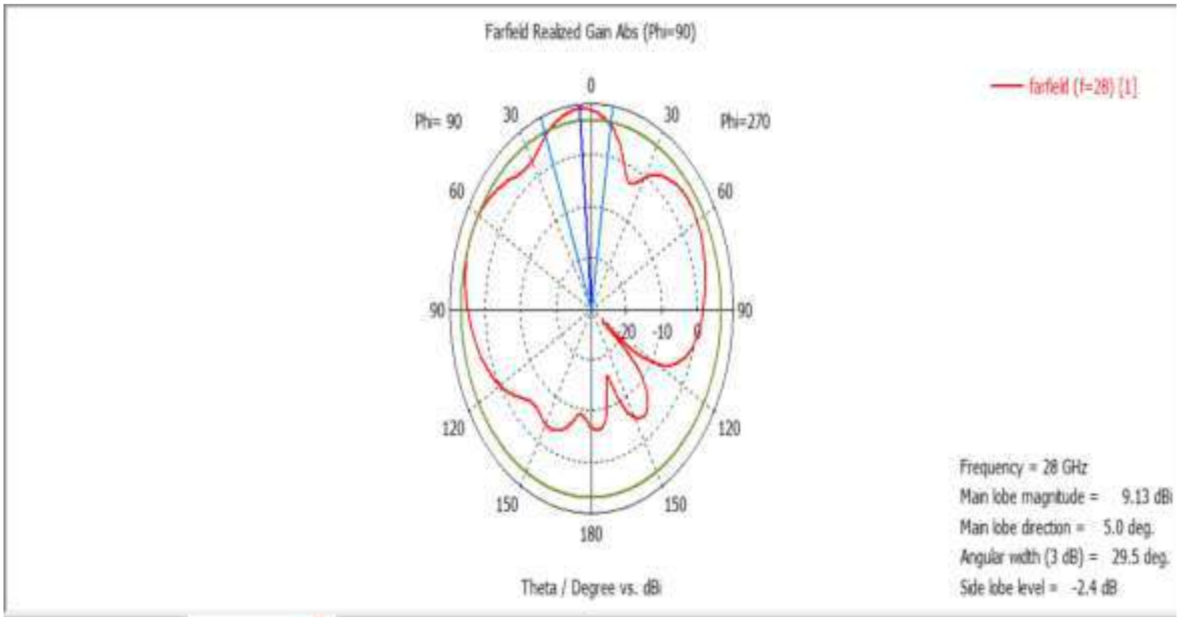


Figure 4.3 Single element antenna 2D radiation pattern for 28 GHz

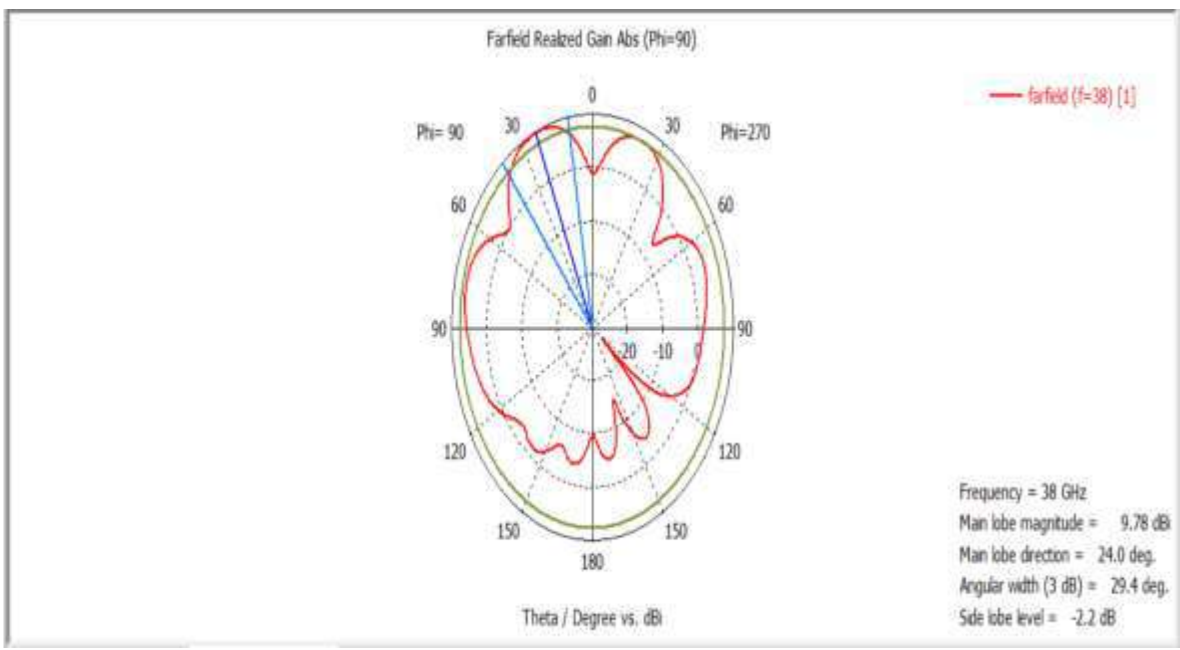


Figure 4.4 Single element antenna 2D radiation pattern for 38 GHz

3D Radiation Pattern:

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 its 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 below at 28 GHz and 38 GHz.

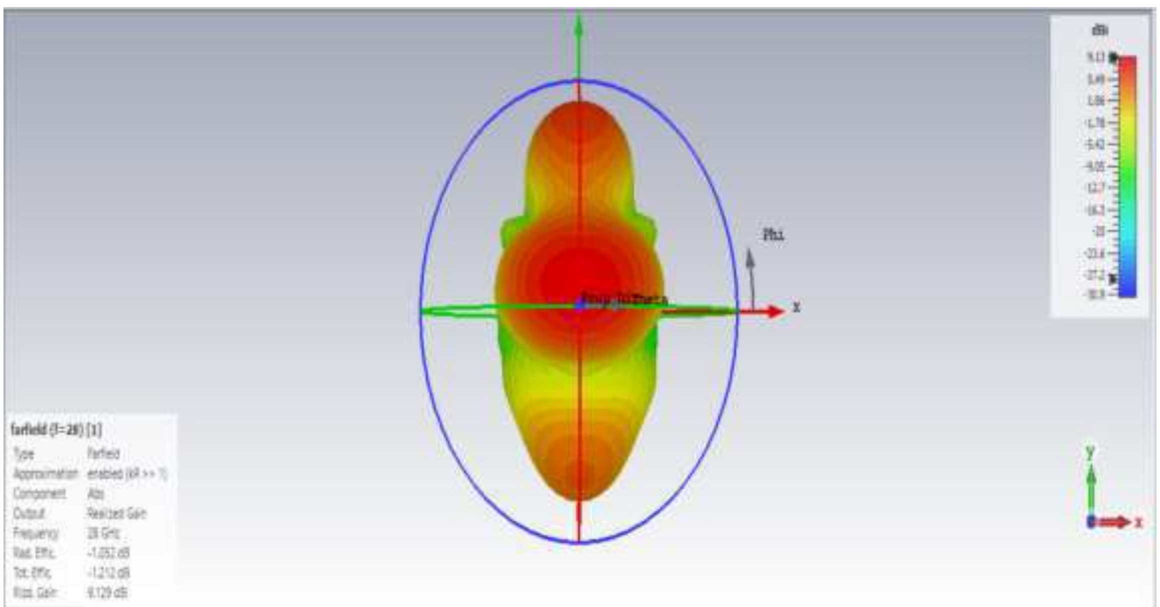


Figure 4.5 Single Element Antenna 3D Radiation Pattern at 28 GHz

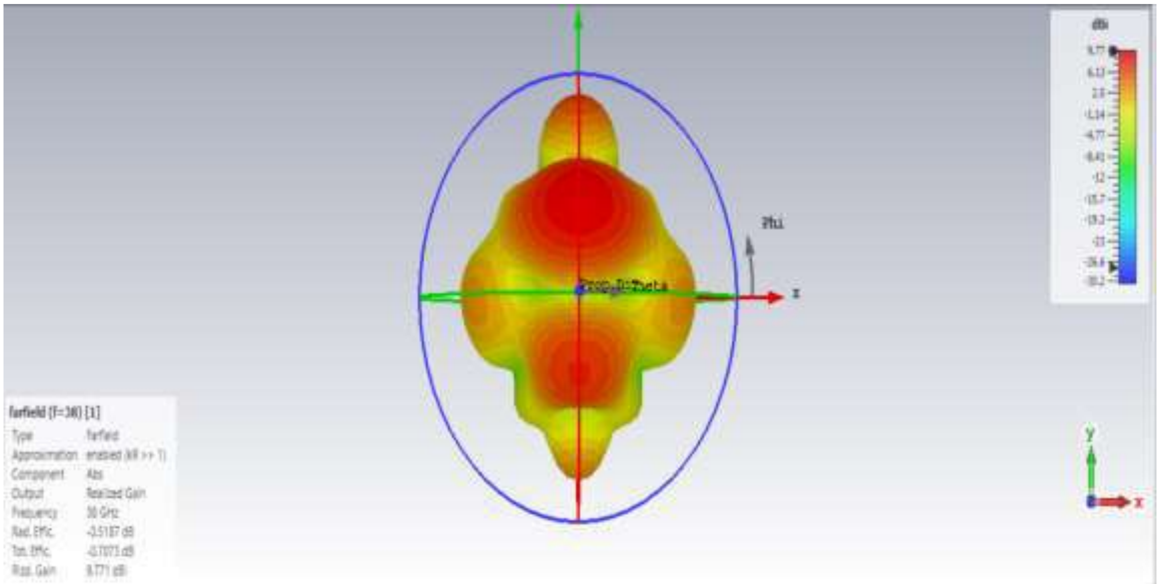


Figure 4.6 Single Element Antenna 3D Radiation Pattern at 38 GHz

Antenna Efficiency

Antenna efficiency is defined as the ratio of the aperture effective area to its actual physical size.The antenna efficiency graph of an antenna is shown below.

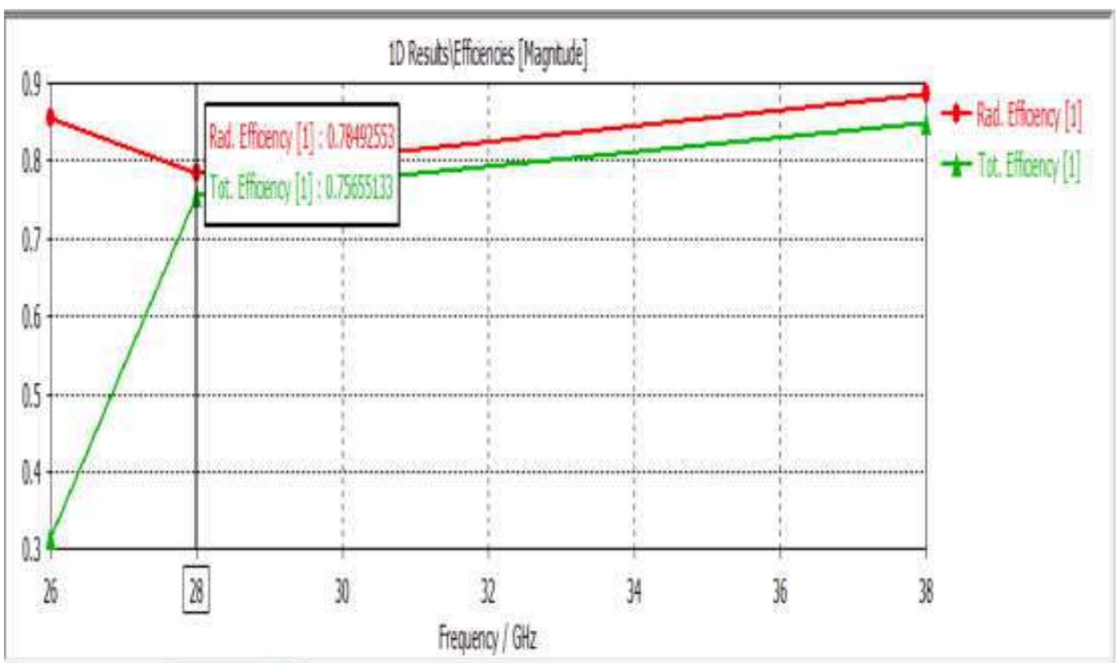


Figure 4.7 Antenna efficiency of single element antenna for 28 GHz

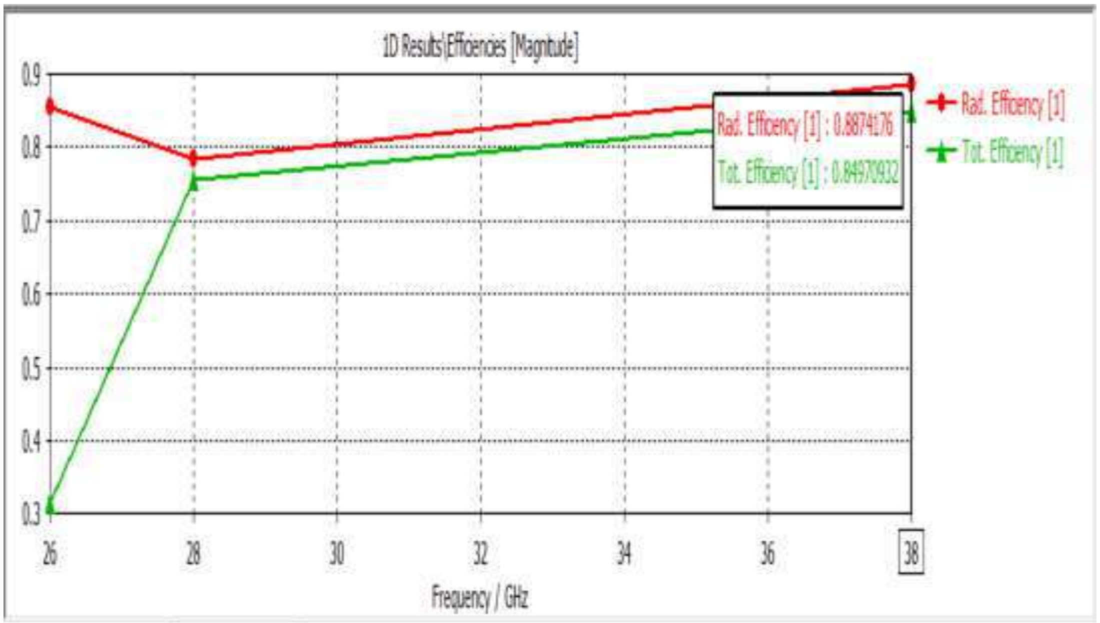


Figure 4.8 Antenna efficiency of single element antenna for 38 GHz

Generally, antenna effectiveness is defined between the relationship of the effective aperture area and its 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%. Above figure 4.7 and 4.8 demonstrate that antenna efficiency is 75% percent for 28GHz and 84% for 38 GHz.

Radiation Efficiency

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 feed line. The standard level of radiation efficiency is 70%. From the figure 4.7 and 4.8 above seen that the radiation efficiency is 78% for 28 GHz and 88% for 38 GHz.

4.2 Final Design Result of Single Element

In table 4.1, the single element antenna full simulation results were displayed. This antenna design shows good loss of return value through entire 28 GHz and 38 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 10.34 dBi and 10.48 dBi that is shows better directional performance. Gain 9.12 dBi at 28 GHz and 9.77 dBi at 38 GHz which are obtained by single element slot antenna. The antenna efficiency and radiation efficiency of this single component antenna reaches 75 and 84 percent throughout the whole band.

TABLE 4.1 Complete Simulation Result of Antenna Single Element

Parameters	Value	Standard [10]
Resonate Frequency	28 GHz ; 38 GHz	As per need
Bandwidth	700 MHz ; 950 MHz	As per need
Return loss (S_{11})	-23.79 dB ; -41.76 dB	less than -10 dB
VSWR	1.1 ; 1.01	2 – 1
Gain	9.12 dBi ; 9.77 dBi	6-9 dBi
Directivity	10.34 dBi ; 10.48 dBi	5-8 dBi
Antenna Efficiency	75% ; 84%	70%
Radiation Efficiency	78% ; 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	Frequency (GHz)	Return loss (dB)	Gain (dBi)	Bandwidth	VSWR	Efficiency
[1]	28 38	-40 -18	3.75 5.06	3.34 GHz 1.39 GHz	--	--
[2]	28 38	-19.3 -18.7	7.02 5.05	900 MHz 480 MHz	1.24 1.26	85% 71%
[3]	28 38	-23.81 -17.09	8.05 8.28	921 MHz 1.045 GHz	1.13 1.32	--
[4]	28 38	-23.6 -27.1	5.41 4.89	1.49 GHz 1.01 GHz	1.14 1.09	90% 84%
[5]	28 38	-30 -22	6 4	1.02 GHz 3.49 GHz	--	--
[6]	28 38	-21.57 -24.59	7.95 8.27	--	--	89% 88%
[7]	38	-24.35	3.23	1.02 GHz	--	--
[8]	28 38	-36 -39	1.27 1.83	2.55 GHz 2.1 GHz	--	78% 76%
This Work	**28** **38**	**-23.79** **-41.76**	**9.12** **9.77**	**700 MHz** **950 MHz**	**1.1** **1.01**	**75%** **84%**

4.4 Result Analysis

The single element antenna full simulation results were displayed. This antenna design shows good loss of return value through entire 28 GHz and 38 GHz band. In comparison, the antenna's VSWR is below than 1.5. And our two frequency bandwidth is 700 MHz and 950 MHz.And gain also quite compared to the recent models of an antenna. Also this antenna directivity is almost 10.34 dBi and 10.48 dBi that is shows better directional performance. Gain 9.12 dBi at 28 GHz and 9.77 dBi at 38 GHz which are obtained by single element slot antenna. The antenna efficiency and radiation efficiency of this single component antenna reaches 75 and 84 percent throughout the whole band. All the papers we compared with did not give all the related values. But we have given the results of all the parameters of the antenna. Analyzing our results shows that our gain and return loss are much higher than the results of the papers we are comparing with our predecessors. Our efficiency is in the average value.. So by analyzing above discussion we can say our antenna is ahead in terms of gain and return loss compared to other papers.

Chapter 5
Conclusion

In response to the rising need for fast and reliable mobile communication devices, a rectangular slotted microstrip patch antenna was developed for high-band 5G applications. The main goal of our research was to enhance the antenna gain along with other radiation characteristics. The proposed antenna was intentionally designed with a single patch for simplicity and aimed to resonate the antenna at the 28 and 38GHz 5G frequency bands simultaneously.

Achievments

This antenna is designed and simulated successfully with 50 ohm probe feed for a dual band patch antenna. The proposed antenna operate below -10dB return loss with the frequency at 28 GHz and 38 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 700 MHz. 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 powerful candidate in future 5G mobile phones.

Limitations

The suggested antenna lacks beam steering capabilities. This would increase its effectiveness when used with a mobile phone.

Future Work Field

It is useful to add beam steering facility to improve the antenna coverage angle. In future we can improve our results by doing array antenna.

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