BACHELOR OF SCIENCE IN ELECTRONIC AND
TELECOMMUNICATION ENGINEERING

An Ultra-compact Multiband Antenna for 5G massive MIMO Applications Below 6 GHz

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CANDIDATES DECLARATION

It is officially acknowledged that the thesis above has not been presented elsewhere for the awarding of any degree or certificate, and it does not contain any assertions that are banned.

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DEDICATION

This thesis work is dedicated to all of our honorable teachers, parents, and all well-wishers.

CERTIFICATE OF APPROVAL

The project entitled “A Compact Multiband Antenna for Sub-6 GHz 5G mMIMO Applications” was submitted by Md. Emdadul Hoque Bhuiyan, bearing ID No: T-181071 & Kazi Fatin Intesar Razin, bearing ID No: T-181060. The format and content of your Electronic and Telecommunications Engineering (ETE) undergraduate thesis, submitted on or before November 22, 2022, to the ETE department at International Islamic University Chittagong (IIUC), have been approved.

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"In the name of Allah, most gracious and most merciful." To Allah (SWT), be the glory that He may bestow upon us His bountiful blessings and guide us with His mercy and wisdom as we journey through life. And may Allah bless and keep the noble Prophet Muhammad (PBUH) who has shown us the way. We owe a great deal to Abdul Gafur, our thesis advisor, who provided insightful suggestions, constant support, and motivation during our time at the university. We want to thank IIUC's department of Electronic and Telecommunication Engineering Chairman, Engr. Syed Zahidur Rashid, for supplying us with top-notch machinery and quickly giving us his expert advice. We are incredibly grateful to Abu Zafar Md for his hard work and devotion. Imran, our thesis advisor. As a group, we owe an outstanding debt of gratitude to our teachers, who always went above and beyond for us during our time in school. And we will never forget the love and encouragement of our parents. We want to thank everyone who had a role, however slight, in completing this thesis, especially our friends and well-wishers.

Abstract

In this paper, we have designed a compact antenna for massive MIMO applications. The design has been carried out using various parameters such as left-hand tweak and right-hand tweak. The simulations were carried out with different hands simultaneously. The design and simulation of the proposed MIMO antenna are performed in the CST Studio Suite. The antenna is designed at an operational frequency of 2.6 GHz with a dielectric substrate and a conducting ground plane (W×L=19×38.2 mm2). The material of the substrate is FR-4 (lossy), with a relative permittivity of 4.3, a height of 1.6 mm, and a loss tangent of 0.025. The material of the ground plane is copper (annealed) with a thickness (t) of 0.035 mm, and the ground plane is cut into a smaller one to achieve a broader bandwidth. The optimized dimensions of the antenna are Wp=17.17 mm and Lp=22.13 mm. The width of the feedline (Flow) connected to the patch is 2.42 mm, and the length (Fl) is 14.93 mm.

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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
CST	Computer Simulator Technology
PCB	Printed Circuit Board
BW	Bandwidth
RL	Return Loss
Q	Quality Factor
RF	Radio Frequency
MICs	Microwave integrated circuits
PTT	Push to Talk
IMTS	Improved Mobile Telephone System
AMTS	Advance Mobile Telephone System
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
GPRS	General Packet Radio Service
MIMO	Multiple Input Multiple Output

Chapter 1

Introduction

1.1 Evolution of Wireless Communication(0G-5G)

Without the need for wires, the transmission may be said to be wireless. It employs a plethora of frequencies and bandwidths for communication. When sending a signal, the sender takes advantage of available bandwidth. To "tune" to the correct frequency and pick up the transmitted signal, the receiver must first determine what range it is operating in. The supplier of a mobile wireless network allocates a unique frequency to each mobile station in the network. The signals on this frequency are presently being sent and received by mobile stations. Motorola unveiled the world's first portable telephone to the public in 1973. NTT established Japan's first commercial, fully automated cellular network that year. In 1981, the Nordic Mobile Telephone (NMT) system was launched in Denmark, Finland, Norway, and Sweden. [1] The next phase is to perfect wireless communication technologies. Wire-Free Telephony for Portable Devices Push to Talk, a protocol implemented by 0G and developed by Technique, was his entry point into the field of telecommunications. The only purpose of 1G networks in the future will be to carry voice calls. Incorporating digital technology and the capacity to broadcast a message, 2G was a rethinking of 1G. With 3G, users have access to a wide range of high-speed internet options. As a successor to 3G, 4G boasts higher throughput and capacity unlike the quality of service. Wireless Internet access is made possible in real-time with 5G networks, which have double the ability of 4G. (WWWW). [2]

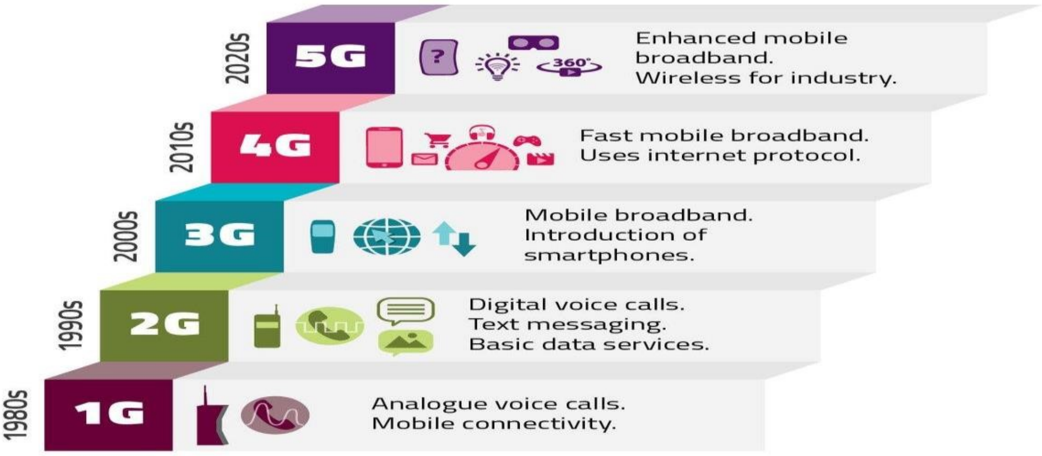


Figure 1.1: Transformation/improvement of interpersonal interaction [50]

1.2 Zero Generation of Wireless Communication (0G)

In the days before cell phones were widely utilized, some people used radiotelephones in their cars to make and receive calls; this technology is what 0G refers to. Because of the success of the present cellular mobile phone technology, wireless mobile systems were developed.

- ✓ Push-to-talk (PTT), also known as "Press to Transmit," is a method used in 0G systems to start a discussion over a half-duplex communication channel, such a two-way radio, without first establishing a connection between the parties involved. When you take the phone out of its dock,
- ✓ Devices using the IMTS (Improved Mobile Telephone Service) protocol emitted a dial tone, providing the appearance to the user that they were communicating with a traditional landline phone rather than a mobile phone.
- ✓ The Advanced Mobile Telecommunications System (AMTS) uses the 900 MHz frequency and solves all the issues of IMTS.
- ✓ Fixed wireless service MTD (Mobile telephony system D) enabled users to access the internet at fast speeds without a traditional phone line. You may have "always on" connectivity to the web with this. [3]

1.3 First Generation of Wireless Communication (1G)

It is often accepted that 1G refers to the first generation of mobile wireless communication technology. The first mobile phone networks appeared in the early 1980s, and the last one went down in the early 1990s. The first cellular network was introduced in 1979 by Nippon Telephone and Telegraph (NTT), a Japanese company with headquarters in Tokyo. Both the Nordic Mobile Telephone (NMT) and the Telephone and Computer Systems (TACS) analog networks were widely used across Europe in the 1980s. Additionally, across Europe, other analog systems were introduced. “This system, built on AMPS technology, was used to deliver telephony services. The AMPS system "transmitted data at 30 kHz across a waveband of 824-894MHz (FDMA) [42] by means of frequency modulation and frequency division multiple access [42].”

1.3.1 Basic features of 1G

- ✓ Allows voice calls
- ✓ speed of 2.4 kbps.

- ✓ Put to use an analog signal.
- ✓ The sound quality of the call is terrible.
- ✓ Unfortunately, battery life is terrible.
- ✓ The phone is really hefty.
- ✓ Capacity is limited.
- ✓ The handoff is unreliable.
- ✓ Inadequate security.
- ✓ We were only given access to a low grade of spectrum efficiency.

1.4 Second Generation of Wireless Communication (2G)

Technology for the second generation of mobile phones, often referred to as 2G, appeared around the end of the 1980s. At the beginning of this year, a revolutionary new digital technology dubbed Global System for Mobile Communication (2G) was released (GSM). Digital signals were the primary emphasis of GSM technology. It's a service that may transmit SMS and MMS messages at a slow rate (in kbps). It can handle frequencies from 30 hertz to 200 kilohertz. After 2G, 2.5G systems, such as GPRS, CDMA, and EDGE, employ packet-switched and circuit-switched domains to deliver data speeds of up to 144 kbps. e.g., GPRS, CDMA, and EDGE.

- **Basic features of 2G**
  - ✓ The system is digital (switching)
  - ✓ SMS services are available
  - ✓ International travel is feasible.
  - ✓ Enhanced security
  - ✓ Voice communication using encryption
  - ✓ Initiation of the Internet with a Lower Data Rate
  - ✓ Consequences of Using a 2G Network
  - ✓ Low data rate
  - ✓ Limited mobility
  - ✓ Smartphones and tablets now have fewer functions.
  - ✓ Fewer potential users and lower hardware power.
  - ✓ Strong digital signals are necessary for 2G to function on mobile phones. [4]

- **GPRS (General Packet Radio Service) 2.5G**

“2.5G, or "second and a half generation," refers to a generation of mobile wireless technology that was developed around halfway between the first generation and the third [42].” The definition of "General Packet Radio Services" is "second and a half generation" The maximum data rate for GPRS is 115 Kbits/s, while the average speed is 56 Kbits/s. AMMS, WAP, and other internet functions like email and web browsing are also included (WWW). Megabytes of traffic transferred is a popular unit of measurement for GPRS data transmission, in contrast to the minutes of connection time used in traditional circuit switching [11].

1.5 Third Generation of Wireless Communication (3G)

The abbreviation "3G" is used to indicate that this is the third generation. It was designed with the help of the ITU standard set, which was created in the year 2000. The primary focus of third-generation mobile networks was on providing lightning-fast data transfer. It employs a high-definition wireless network to enhance sound quality. It also has TV/Video on Demand and International Roaming capabilities. With a 2100MHz frequency range and a 15-20MHz bandwidth, it's perfect for HD streaming and video chats. [4]

1.5.1 Basic features of 3G

- ✓ The maximum throughput is 2 Mbps.
- ✓ Superior throughput and bandwidth for modifying web-based software and media assets.
- ✓ More quickly conveying ideas is another benefit.
- ✓ Permit the receiving and transmission of enormous email attachments.
- ✓ It offers enhanced security, video conferencing, and 3D gaming.

1.6 Fourth Generation of Wireless Communication (4G)

“To download at speeds of up to 100 Mbps, 4G makes use of the capabilities of the fourth-generation of wireless networking technology [42].” The benefits of third-generation (3G) wireless technology are combined with those of multi-Media in the fourth-generation (4G) wireless standard, enabling for smoother video streaming of television shows and faster data transportation. As a component of 4G technology, LTE has become more popular (Long Term Evolution). [5]

The development of 4G is being pushed in order to fulfill the QoS (Quality of service) and rate needs of future applications like Multimedia Messaging Services (MMS), wireless broadband access, key services like data and voice, and other bandwidth-intensive services. [6]

1.6.1 Basic features of 4G

- ✓ It provides high-quality video streaming at rates of up to 1Gbps and speeds as high as 10Mbps.
- ✓ It combines the best features of both Wi-Max and Wi-Fi.
- ✓ It has a high level of security.
- ✓ It has a greater impact on battery life.
- ✓ Implementing it effectively is challenging.
- ✓ “It requires sophisticated gear to do [7].”

1.6.2 Extension of 4G LTE as 4.5G

4.5G wireless technology has the following properties. It's an abbreviation for "services beyond the scope of standard mobile broadband." It's a development on top of 4G LTE that allows for as much as 300 Mbps in download speeds. As the number of connected devices grows, so does the significance of the IoT.

- ✓ It's The efficient networking of IoT devices is made possible by the development of mobile broadband data rates on the paired and unpaired spectrum.
- ✓ It's a must-have for guaranteeing the public's safety, which is a top priority.
- ✓ The technology enables LTE transmission.
- ✓ “LTE Advanced Pro 3GPP is the industry standard in this respect [42].”
- ✓ The maximum downlink data rates are 1 Mbps (LTE-M) and 170 kbps (NB-IoT)
- ✓ Top speeds in the uplink direction (LTE-M): 1 Mbps; LTE-A: 250 kbps (NB-IoT).
- ✓ The data rate for LTE-M is 1.08 Mbps (1.4 MHz carrier BW), whereas that for NB-IoT is 180 kHz (200 kHz carrier BW). [14] “1.7 Fifth Generation of Wireless Communication (5G) [42].”

5G, short for "Fifth Generation," is a term that has been in use since the latter part of 2010. 5G technology has various benefits, two of which are improved connectivity and expanded range. 5G's primary focus is the global wireless Internet (WWW). Users may anticipate lightning-fast connections and seamless multimedia experiences on 5G networks. The LTE-Advanced networks pave the way for the supercharged 5G networks of the future. Millimeter waves and an unlicensed data band are used by 5G technology to achieve a higher data rate. [8]

1.7.1 Basic features of 5G

- ✓ "It strongly backs the WWW (Wireless World Wide Web)
- ✓ It is able to deal with a significant quantity of data in a timely and effective manner.
- ✓ Massive volumes of data may be sent at a Gbps pace.
- ✓ Offers top-notch support for a variety of media formats, including newspapers and television programs in high definition (HD).
- ✓ In terms of data transmission speed, it is an improvement over its predecessors.
- ✓ High-resolution audio and video, quick call connection times, user-friendly multimedia, text, voice, and video functions, and more all come standard on today's top-tier smartphones.
- ✓ It increased the number of multimedia services available.
- ✓ Affordable price per bit.
- ✓ It consumes more battery power.
- ✓ Implementing it effectively is challenging.
- ✓ It requires sophisticated gear to do [42]."

Table 1.1: Comparison of Different Wireless Communication Technology Generations [10]

Generation→ Features↓	**0G**	**1G**	**2G**	**3G**	**4G**	**5G**
Year	1960-1970	1970-1980	1980-1990	1990-2000	2000-2010	2015onwards

Switching	Circuit	Circuit	Circuit and packet	Packet except for circuit for an air Interface	Packet	Packet
Speed	Below 1kbps	2.4kbps	64kbps	2mbps	200mbps-1gbps	1gbps and higher
Technology	PTT, MTS, IMTS, AMTS	Analog Cellular,	Digital Cellular	Broadband CDMA, IP	Unified IP & seamless combination n of broadband LAN, WAN,	4G+ WWWW
					WLAN, PAN	
Services	Pre-cellular systems	Voice only	Digital voice and short messagi ng packetized ed data	Integrated high-quality audio, video, and data	Dynamic informatio n access , wearable devices	Dynamic information access, wearable devices with AI capabilities
Multiplexing	FDMA	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Core Network	PSTN	PSTN	PSTN	Packet Network	Internet	Internet

1.8 Key spectrum activities to enable 5G are being driven by the FCC.

The FCC is leading the charge on crucial spectrum actions to enable 5G.

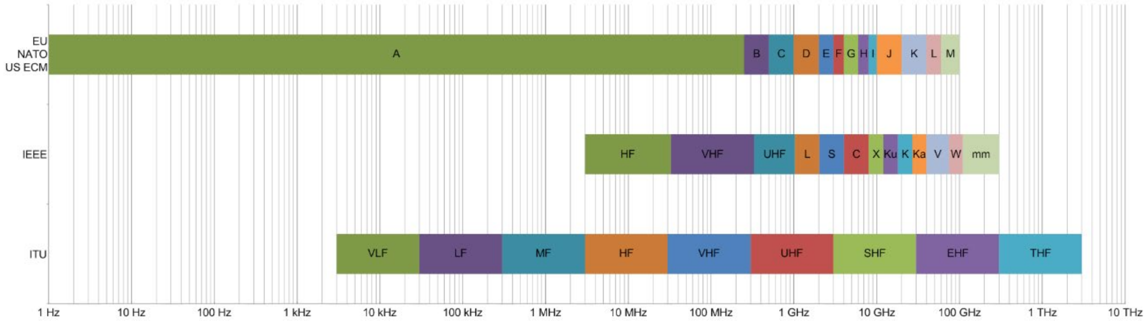


Figure 1.2: Spectrum for 5G

1.8.1 Low-Band

The FCC has taken the initiative on crucial spectrum moves that will make 5G possible.

- ✓ “Part of the 600 MHz license was auctioned off after the assigning phase, and the sale made $19.8 billion.

- ✓ Total allocated spectrum is 70 MHz over two channels, with an extra 14 MHz accessible for unlicensed use.
- ✓ Spectrum availability corresponds to 5G [42]."

1.8.2 Mid-band

Residents Broadband Radio Services

- ✓ "Specifically, by introducing a brand new 150 MHz of spectrum in the 3.5 GHz band for three-layer sharing with current operators (PAL1, GAA2).
- ✓ In 2017, the FCC issued PAL instructions that prepared them for 5G.
- ✓ To further an LTE-based ecosystem, the CBRS Alliance was formed.
- ✓ Specifically, the FCC has received inquiries on the frequency bands of 3.7–4.2 GHz and 5.9–7.1 GHz [42]."

1.8.3 High-Band

The Spectrum Frontiers Court first handed down a decision in 2016 and then again in 2017.

- ✓ "Several new millimeter-wave channels are becoming available around 11 GHz.
- ✓ Seventy percent of newly released music is distributed illegally or without permission. Always in agreement.
- ✓ The FCC has advocated the use of additional spectrum nominations designated for IMT-2020.
- ✓ You might expand your coverage by adding the frequencies 24.25-24.45 GHz, 24.75-25.25 GHz, and 42-42.5 GHz [42]."

1.8.4 Managing the cutting edge of 5G millimeter wave spectrum

Because of licensed and unlicensed spectrum sharing, more frequencies may be utilized.

Licensed Spectrum

- "27.5 GHz – 28.35 GHz
- 37.6 GHz – 38.6 GHz
- 38.6 GHz - 40 GHz [42]."

Shared and unlicensed spectrum

- "37 GHz– 37.6 GHz
- 64 GHz- 71 GHz [42]."

1.8.5 Spectrum of 5G in Europe

Concentrate on the 26 GHz range and the middle band (3.4-3.8 GHz) (24.25-27.5 GHz) The European Commission's Radio Spectrum Coordination Unit (RSCU), the European Telecommunications Standards Institute (CEPT), and key European Member States are leading legislative moves to speed up the implementation of 5G throughout the EU.

- ✓ "The 3.4–3.8 GHz and 26 GHz bands have been well-supervised, and auctions are scheduled for 2017–2018.
- ✓ The United Kingdom's 5G plan was made public in March of 2017.
- ✓ Ofcom had intended to auction off 150 MHz of spectrum in the 3.4–3.6 GHz band in 2017–2018, and 110 MHz of spectrum in the 3.6–3.8 GHz band in 2018–2019.
- ✓ For efficient and timely 5G planning, Ofcom has established a platform to collaborate on the availability of the 26 GHz spectrum.
- ✓ The Italian government had intended to auction off 700 MHz, 3.6–3.8 GHz, and 26.5–27.5 GHz spectrum in 2018.
- ✓ The Irish government successfully auctioned off 350 MHz of radio spectrum for 5G connectivity.
- ✓ In 2018, the Spanish government issued permission for the 3.6 GHz-3.8 GHz spectrum in response to market demands and operator needs.
- ✓ Spain's efforts are focused on the 26 GHz frequency range. By the end of 2018, users will have access to at least 1.4 GHz of bandwidth.

A number of other nations, including Austria, Belgium, and Switzerland, are intending to introduce their own in the 2018–2019-time frame [42]."

1.9 Antenna Basics

An antenna is a special kind of transducer that can both receive and send radio frequency electromagnetic radiation (RF). Most antennas fall into one of two categories: receivers, which take in radio waves and transform them into usable alternating current, or AC, for the device, or transmitters, which take in AC from the device and then broadcast them. Most wireless applications use microstrip patch antennas because of their small size and high performance. In general, the microwave frequency range is the solely applicable frequency for microstrip patch antennas.

1.9.1 Frequency

The standard definition of frequency is the occurrence of a specific event within a certain time frame. When we speak about something's frequency, we are referring to the total number of times it has occurred over a certain amount of time in a given period of time. Conventional wisdom states that frequency is "the number of recurrences of a signal over a specific time period" (1 second). A periodic signal is one that occurs at regular intervals of time, denoted by the symbol "T." The frequency of a periodic signal is proportional to its period in time (T). Figures 1.3 and 1.4 depict frequency distributions. The term "frequency" is used in the engineering field to describe the rate of repetition of oscillatory and vibratory phenomena such as radio waves, sound signals, mechanical vibrations, and light. The SI unit of frequency is the Hertz, named for the German scientist who invented it (Hz). The hertz scale is used to indicate the frequency of an event or signal in terms of the number of cycles it undergoes every second.

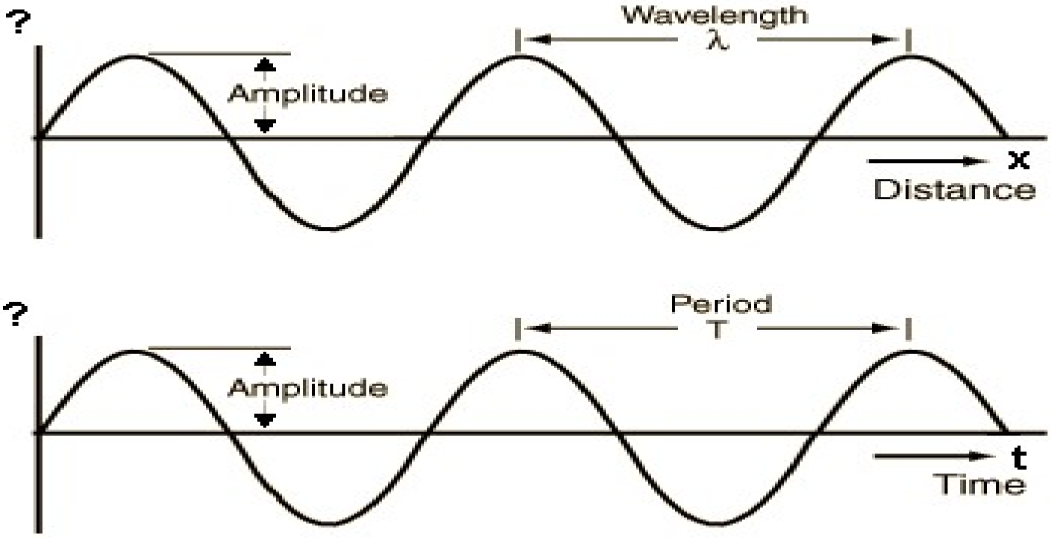


Figure 1.3: Wave frequency diagram

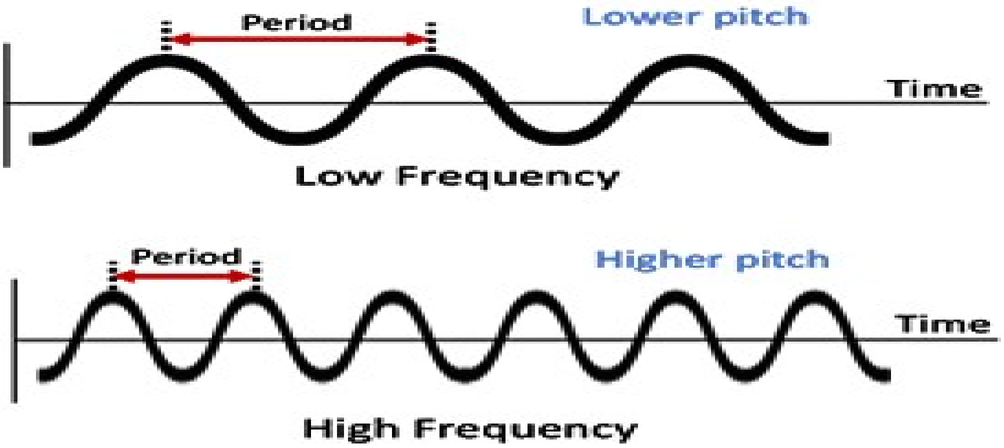


Figure 1.4: Spectrum of Sound Frequencies

1.9.2 Bandwidth

If you want to send a lot of data from one place to another via the Internet or a network, you need a lot of bandwidth. An antenna's bandwidth is the frequency range across which it can transmit or receive signals effectively. It's common knowledge that bandwidth is a significant consideration for picking an antenna.It is crucial to remember that some antenna types, for example, have relatively narrow bandwidths and are thus unfit for wideband operation. Figure 1.5 shows a frequency spectrum representing the bandwidth.

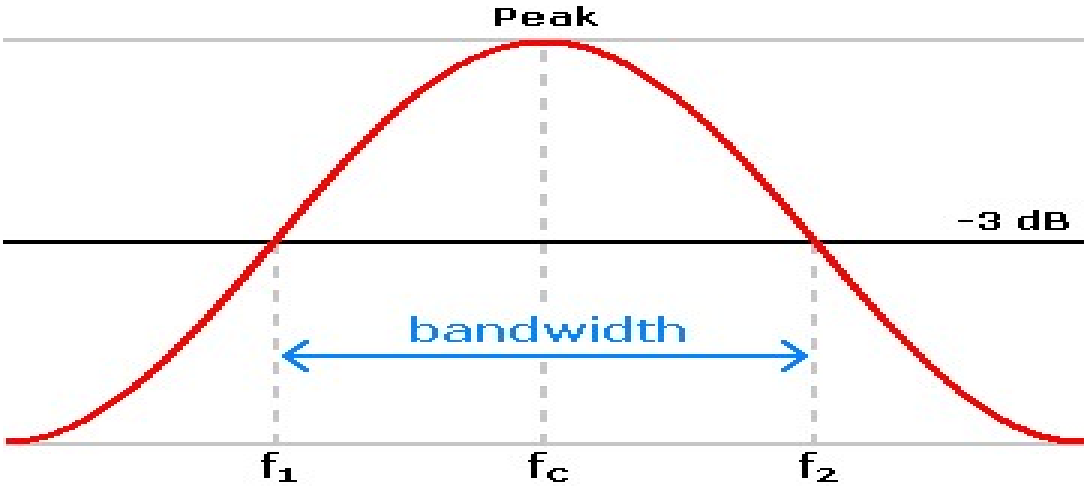


Figure 1.5: Diagram of Bandwidth

1.9.3 Input Impedance

This voltage-to-current ratio at the antenna's terminals determines the antenna's input impedance. It's an important parameter for characterizing the antenna's resonance frequency. 'Actual' and 'imaginary' input impedance components are distinguished.

“The input impedance is a representation of the basic components that contribute to the input and hence the internal dissipation or creation of power. The imaginary part of the input impedance, sometimes called reflected power, represents the energy that is localized inside the antenna's near field. A resonant antenna has no input impedance, either in the actual or fictional world. Depending on its size, an antenna's input impedance will vary. The impedance symbol, Z, is composed of two parts: the basic part, which is made up of the radiation resistance Road and ohmic losses Rohmic of the antenna, and the reactive component, which is made up of the radiation resistance Road and ohmic losses Rohmic of the antenna, and a fraction X [42].”

1.9.4 Impedance Matching

“Impedance matching, as the term is commonly understood, takes place when "the approximate value of a transmitter's impedance matches the approximate value of a receiver's impedance or vice versa." In wireless communication, the antenna and electronics must have an impedance that is well-matched to one another. In principle, if the antenna's impedance, the transmission line's impedance, and the electronics' impedance are all the same, then the possible power will be transferred from the antenna to the receiver or transmitter. Antenna tuning or matching entails matching the antenna's impedance to that of the electronics throughout the desired frequency range. The frequency range that encompasses the bandwidth, referred to as the antenna impedance, is near 50 Ohms for a certain VSWR, while VSWR defines the quality of the match. When it comes to output, a resonant device is one that excels only across a narrow frequency range. When the impedances of two antennas are matched, the resulting resonance results in higher signal strength. As can be shown later, impedance matching is essential [42].”

- ✓ If the feedline's impedance matches that of the source, power will be delivered to the feedline without being lost.
- ✓ If the antenna has the same impedance as the feedline, then the power may flow in both directions.
- ✓ A receiver's antenna has to have an output impedance that is compatible with the amplifier's input impedance.
- ✓ Transmission line impedance and the output impedance of the transmitter amplifier should be in phase with the antenna's input impedance [15].

1.9.5 Directivity and Gain

“The word "directivity" is used to characterize an antenna's enhanced performance in either transmission or reception in relation to the direction from where the signal originated. Gain is usually described as the ratio of the antenna's power output in response to a Fairfield source along the antenna's beam axis to the power output of a theoretical lossless isotropic antenna. The word "directivity" is used to characterize an antenna's enhanced performance in either transmission or reception in relation to the direction from where the signal originated. Gain is usually described as the ratio of the antenna's power output in response to a Fairfield source along the antenna's beam axis to the power output of a theoretical lossless isotropic antenna [42].” It is a well-known fact that gain and directional quality are related in an inverse fashion. Higher directivity explains the connection between a standard light bulb and a spotlight. When compared to a standard 100-watt incandescent bulb, the light output of a spotlight of the same wattage will be more concentrated in a single direction. The light from an ordinary bulb lacks the "directivity" of a spotlight. There are some parallels between the spotlight and a highly directional antenna. The directivity's usefulness is measured by the gain. In mathematical terms, the gain is the product of directional effectiveness. The efficiency of the antenna is a new dimension added to the gain-directivity relationship [16]. The relationship between Gain and Directivity is seen in Figure 1.6.

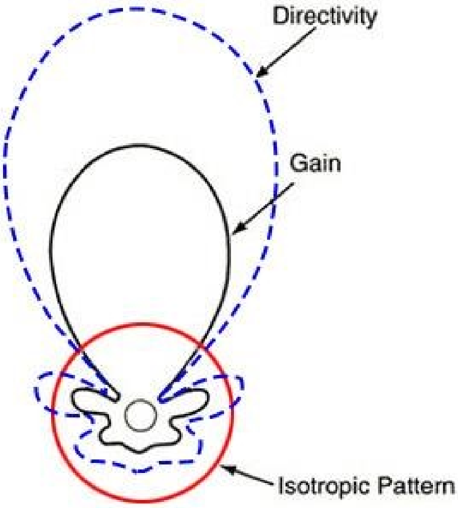


Figure 1.6: Schematic Representation of Gain and Directivity [16]

1.9.6 Radiation Pattern

The angular dependence of the radio wave strength at an antenna is described by its "radiation pattern" (also "antenna pattern" or "far-field pattern"). The radiation pattern characterizes, at a certain distance from the antenna, the relative intensity of the radiated field in different directions. The radiation pattern is also known as the reception pattern since it shows how successfully an antenna can take up signals. While the radiation pattern is not simple to depict, it is nevertheless three dimensional. In Figure 1.7, we can observe the radiation pattern. It also takes time to take a three-dimensional readout of a radiation pattern. The results of radiation measurements are often shown as a cross-section across a three-dimensional structure. Both the rectangular and polar representations of these design parameters are acceptable. [13].

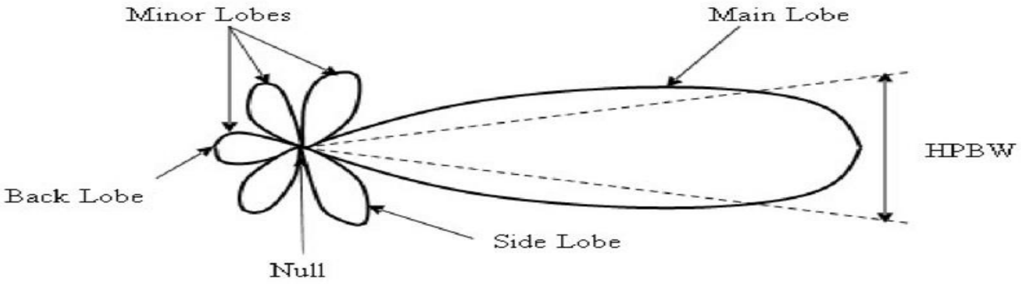


Figure 1.7: Pattern of Radiation Diagram [16]

1.9.7 Voltage Standing Wave Ratio (VSWR)

The voltage standing wave ratio is a metric for gauging how efficiently radio frequency (RF) power is transmitted from a generator to a consumer (VSWR). The standing wave ratio is the ratio of the strongest wave to the weakest wave (SWR). Definition of voltage standing wave ratio - the proportion of a voltage's standing wave to the voltage (VSWR). The real value of an antenna's voltage standing wave ratio (VSWR) is always going to be on the positive side. With a reduced VSWR, more energy can be transferred from the transmission line to the antenna. Required VSWR of 1 or less. Without any electricity being reflected by the antenna, [13] that is the best-case situation. Figure 1.8 depicts the voltage-switch-gain (VSWR) ratio.

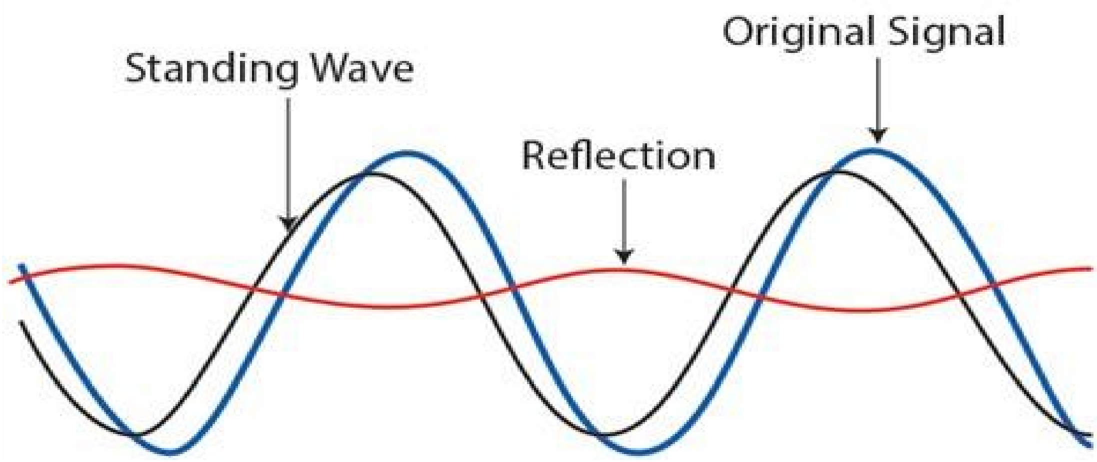


Figure 1.8: Voltage Standing Wave Ratio (VSWR) [16]

1.9.8 Return Loss (RL)

Return Loss measures how many incoming radio waves are sent away by an antenna relative to how many are picked up. Its value, in decibels (dB), is defined in relation to a short circuit (100 percent rejection). When there is a mismatch between an antenna and its feedline, the result is a loss in signal transmission (called "return loss") (RL). The algorithmic ratio quantifies, in decibels, the antenna's power reflection in relation to the transmission line's input power. There is a direct correlation between VSWR and RL. In fact, the antenna parameter S11 is brought up more often than any other. S11 is only a return loss and nothing more (RL). With S11 = 0 dB, the antenna does not radiate any power and instead reflects it back. When 3 dB of force is applied to the antenna, the reflected power will be -3 dB if S11 = -6 dB. For RL or S11 to be less than -9.5 dB, the VSWR must be less than 2. In this thesis, an RL of -10 dB is regarded as sufficient [13].

1.9.9 Polarization

Design and Fabrication of an Emitted Wave Electric Field Microstrip Patch Antenna. The polarization of the antenna may change depending on the intensity and direction of the electric field. An antenna is said to be linearly polarized when all of its electric field components have the same magnitude and phase. An antenna is considered to be circularly polarized if its polarization components have the same magnitudes but opposite phases. To exchange information, two linearly polarized antennas' projected electric fields must be in phase with one another.

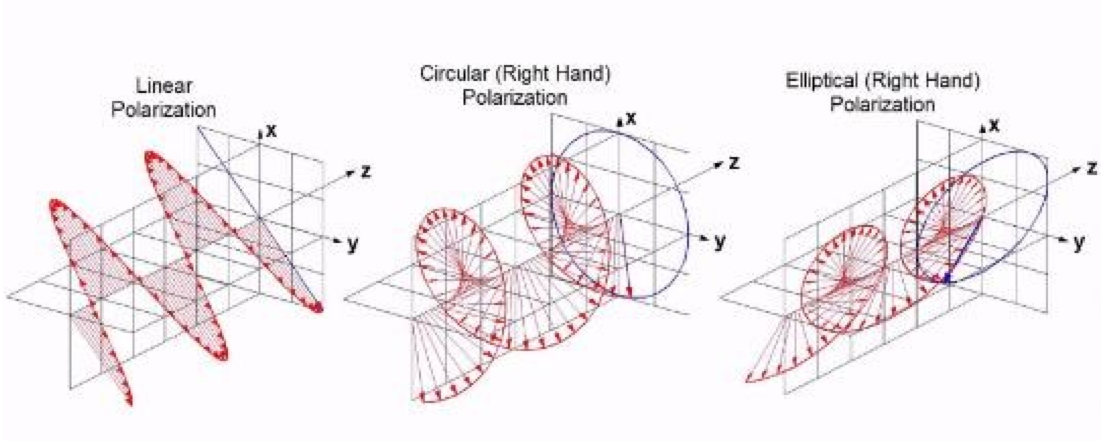


Figure 1.9: Linear, Circular, and Elliptical Polarization.

However, a circularly polarized antenna can talk to any linear antenna. In contrast to the circular antenna's lack of directionality, the linear antenna's increased output is due to its ability to focus its radiation in a single plane rather than dividing it between its two elements. Tag antennas should be circularly polarized to allow for reading from any direction [16], while reader antennas can be either linear or circular, depending on the use case. It is clear from Figure 1.9 that there are three distinct polarization kinds.

Chapter 2

Microstrip Antenna

2.1 Microstrip Patch Antenna

As can be seen in Figure 2.1, a microstrip patch antenna consists of a ground plane and a radiating patch on opposing sides of a dielectric substrate. Patches made of conductive metals like copper or gold may be fabricated in any shape or size. Typically, the dielectric substrate is photo-etched to reveal the radiating patch and feed lines. The patch is often a conventional shape like a square, rectangle, circle, triangle, or ellipse to enable analysis and performance prediction. Fringing fields between the patch edge and the ground plane cause radiation from microstrip patch antennas. If an antenna is mounted on a thick dielectric substrate with a lower dielectric constant, its efficiency, bandwidth, and radiation performance may all be greatly improved.

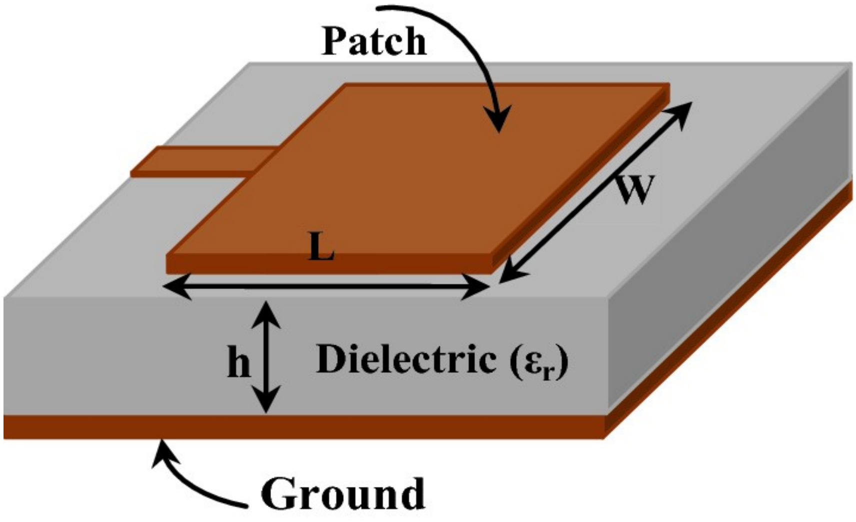


Figure 2.1: Microstrip Patch Antenna Design and Construction

A giant antenna would be required for such an arrangement, however. Building a small Microstrip patch antenna necessitates the use of higher dielectric constants, can lead to low efficiency and a small bandwidth. [16]

2.1.1 Microstrip antenna Feed Techniques

Here are some illustrations of common approaches of feeding a microstrip antenna.

- “Feed for Microstrip Lines
- Connector Type: Coaxial / Probe Feed
- Focused Input Device with Coupled Aperture

- Proximity Coupled Feed [42].”

2.1.2 Microstrip Line Feeding

“This feeding method involves trimming a microstrip transmission line to a precise fit along the patch's outside border [42].” As can be seen in Figure 2.2, the microstrip feed line is used.

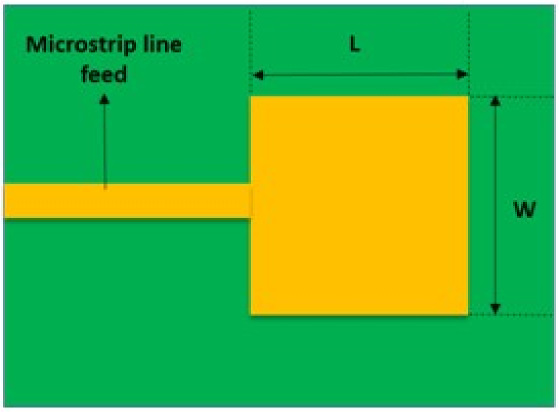


Figure 2.2: Diagram of Microstrip Line Feeding

2.1.3 Coaxial or Probe feeding

The coaxial connection's inner conductor is grounded, while the outer conductor is linked to the radiating patch via the substrate. A representation of coaxial feeding is shown in Figure 2.3.

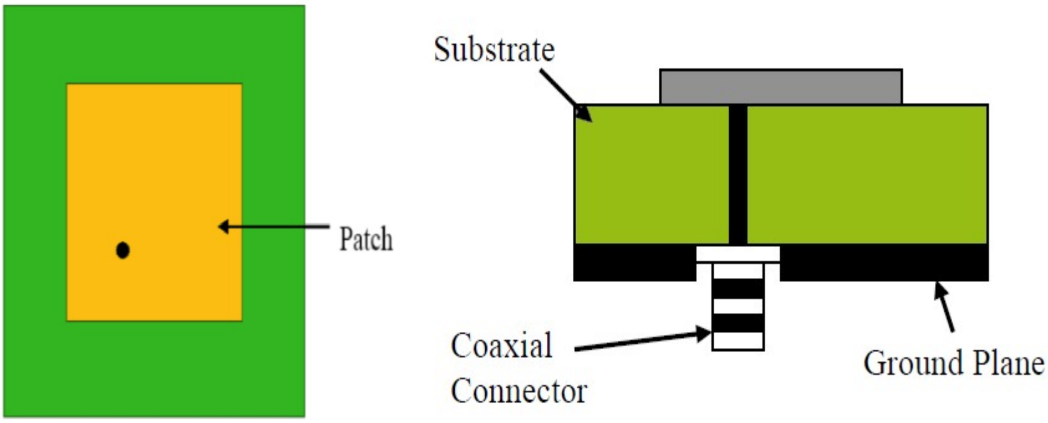


Figure 2.3: Diagram of Coaxial / Probe feeding.

2.1.4 Focused Input Device with Coupled Aperture

The aperture coupling using such a feed consists of two substrates separated by a ground plane. The ground plane separates the radiating patch and microstrip line in the bottom substrate. To create the coupling, a tiny slit or aperture is carved out of the ground plane to allow for electrical conduction. Figure 2.4 is an example of an aperture-coupled feed.

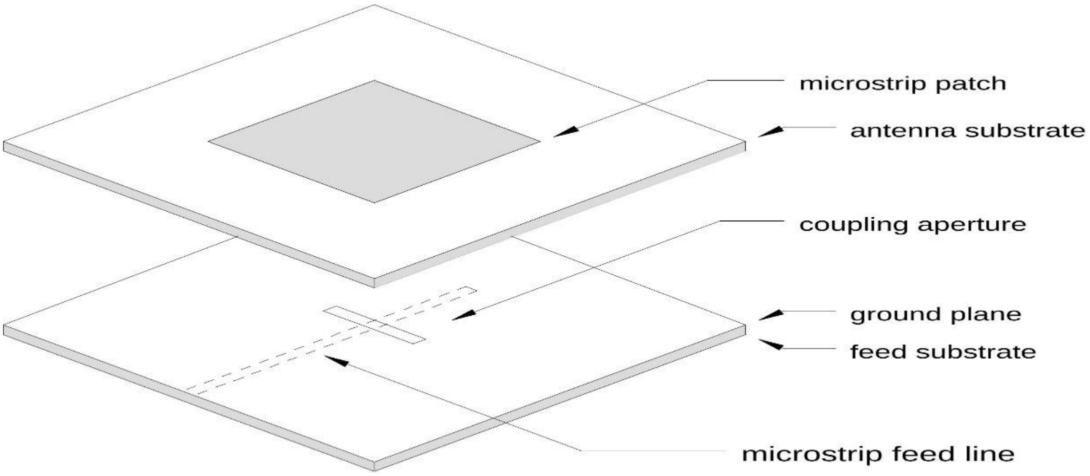


Figure 2.4: Diagram of Aperture-Coupled Feed

2.1.5 Proximity Coupled Feed

In other terminology, it is referred to as Electromagnetic Coupled ECMSA. It, too, consists of two substrates. The microstrip feed line is positioned between the radiating patch and the top substrate in this layout. It is seen in Figure 2.5.

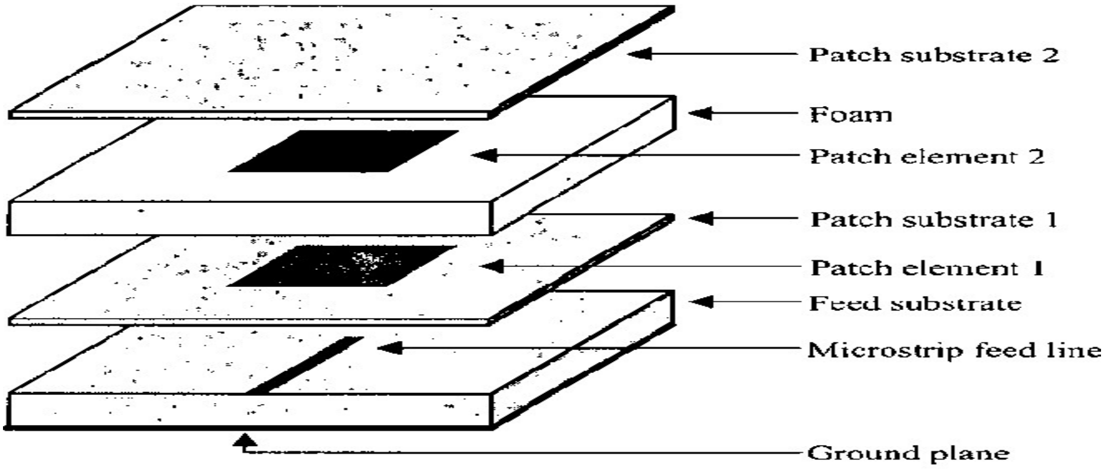


Figure 2.5: Proximity-coupled feed network diagram

2.1.6 Advantages and Disadvantages of Microstrip Antenna

Because of its high gain and small size, microstrip patch antennas find widespread use in wireless networks. That's why gadgets like cell phones and pagers have such high-quality antennas. Thanks to their small size and adaptability, microstrip patch antennas are often utilized for telemetry and communication aboard missiles.

2.1.6.1 Advantages of the microstrip antenna

- ✓ Microstrip antennas have the advantages of being compact, lightweight, and easy to mass-produce in large numbers due to their low production cost.
- ✓ Because of their thin profile, they may be easily molded into the form of the host surface.
- ✓ Both linear and circular polarization are supported.
- ✓ For use with microwave integrated circuits, microstrip antennas are a simple addition (MICs).
- ✓ They may function on two or even three separate frequencies at once.
- ✓ They have mechanical resilience when mounted on firm surfaces.

2.1.6.2 Disadvantages of the Microstrip antenna

- ✓ Microstrip antennas perform poorly in high frequency ranges.
- ✓ Inefficient.
- ✓ Have a poor gain.
- ✓ Extraneous radiation from feeds and junctions is a problem for them.
- ✓ Besides its inadequate end-fire radiator and tapered slot antennas.
- ✓ They aren't equipped to deal with large quantities of power.
- ✓ stimulation by ocean waves' surface tension.

“The antenna quality factor of microstrip patch antennas is rather high (Q) [42].” Q is a representation of the antenna's losses; a high Q means the antenna has a limited bandwidth and is inefficient. Q may be decreased by increasing the thickness of the dielectric substrate. Surface waves absorb a rising share of the source's total power. Since this surface wave contribution is dissipated at the dielectric bends, it might be seen as a loss of power and an unfavorable change in characteristics. [16]

2.2 Design Tool

The properties of design tools are listed in this section.

2.2.1 CST Microwave Studio

If you need a 3D high-frequency structure simulator, CST MICROWAVE STUDIO is your best option (CST MWS). High-frequency components such as antennas, filters, couplers, planar and multi-layer structures, and more may all benefit from the fast and precise analysis offered by CST MWS, which can also be used to address problems with electromagnetic compatibility and electromagnetic induction. Solution algorithms in both the Time Domain and the Frequency Domain are included in the program. Import filters for particular CAD files and SPICE parameter extraction provide more flexibility and faster design iteration. CST's computational solutions for electromagnetic design and analysis are reliable and efficient.

2.2 Motivation

Since its inception, wireless communication's popularity has increased as a result of the many benefits it offers, including its cheap cost, flexibility, mobility, and so on. This has resulted in a dramatic increase in the use of mobile networks and an explosion in the volume of data sent over these networks during the last three decades. The IoT has once again widened the scope of these requirements. In response to this growing need, the telecom sector has developed new generations of standards almost every decade. To accommodate the needs of enabling connections for more than 100 billion wireless devices, millisecond latency, data rates of 10 Gbps, and the internet of things [38], the result is the 5th generation (5G), which is expected to be rolled out in the early 2020s. We created an antenna to combat path-loss at high frequencies, a major challenge to the widespread adoption of 5G.

2.3 Essence

For example, the telecommunications industry is one that is constantly evolving. A new generation appears about every ten years. Prior to it, there was 5G, which is the focus of several studies. The leap from 4G to 5G wireless networks is a direct result of the explosion in mobile data use (5G). The fifth generation (5G) of wireless technology is the successor to 4G/IMT-Advanced. The increased capacity of 5G over the current 4G will allow for a more significant number of users on wireless networks, which in turn will make it possible to link a more substantial number of devices, larger machines, and other IoT gadgets (IoT). Since antennas are essential for wireless communication, it's crucial to design antennas that work with 5G networks. Due to its unique collection of features, the microstrip patch antenna has become the most used kind of antenna in contemporary wireless communication. Because of its reduced size, this antenna design is well-suited for handheld gadgets with limited screen real estate. Microstrip antennas may be etched with ease into a printed circuit board. Microstrip patches are readily etched and may take on a number of forms, including rectangles, squares, and triangles. They may be mass manufactured because of their low production costs. They're compatible with many different radio frequencies (dual, triple). They are consistent with either linear or circular polarization. Their weight is manageable. All of the current 4G networks use frequencies below 6 GHz for their data transmissions. However, there is not enough spectrum available in these bands at the moment [38] to support 5G. As a result, we have to go up to the higher frequency bands, which range from 6 GHz to 300 GHz. Accordingly, the Federal Communication Commission has allocated the 3.4-3.6 GHz band, the 5-6 GHz band, the 24.25-27.5 GHz band, the 37-40.5 GHz band, and the 66-76 GHz spectrum for 5G wireless communication [39]. Studies on the development of high-gain microstrip patch antennas for 5G communication at 28 GHz [40] and 38 GHz have been conducted. Not all of the antennas cover the whole 28 GHz and 38 GHz bands as stated by the FCC, and some of them are too big to work with 5G mobile phones. The development of an antenna that operates in both the 28 GHz and 38 GHz bands while still being compatible with 5G handsets is, therefore, essential.

Chapter 3

Literature Review

3.1 Paper Review

This section discusses the study of other scholars that is relevant to this thesis, "Bandwidth Enhancement of a Microstrip Patch Antenna for 5G Applications," and will be an essential part of doing successful 5G research using the present antenna. Design and modeling of a better-performing, easy-to-fabricate antenna.

1. Research Paper on "A 4-element MIMO antenna with orthogonal circular polarization for sub-6 GHz 5G cellular applications."

Dual-band This study suggests a multi-input multiple-output (MIMO) antenna with orthogonal circular polarization for 5G use at frequencies below 6 GHz. Antennae typically have a feed line and a radiating slot. In order to create CP, an elliptical ring slot of variable width is used, as are feed lines of varying length. Orthogonal CP radiation may be emitted from the front and back of a ring slot antenna at the same time. Single-antenna frequency range (3.6–3.8 GHz). Mirrored parts surround each individual MIMO antenna element. Orthogonal CP is a result of MIMO. This MIMO antenna is capable of transmitting LHCP and RHCP in opposite directions (= 0° and 180°) at the same time. There are three lines in a strip on the ground plane that connect the grounds of the antenna elements. The MIMO antenna provides high isolation and CP gain over the whole frequency range (3.4-3.8 GHz). The channel capacity loss and envelop correlation coefficient are used to evaluate MIMO functionality. Various experiments on antenna performance are conducted in close proximity to left-hand and right-hand phantom models to analyze the user's hand, with encouraging results. The antenna's features qualify it for use with 5G mobile networks. [17]

2. Research Paper on "Wideband Decoupled 8-Element MIMO Antenna for 5G Mobile Terminal Applications."

A wideband decoupled dual-antenna pair is designed using CM theory for application in 5G mobile terminals. A combination of parasitic strips and distributed grating isolation (DGS) allows for both high isolation and broadband. The proposed decoupled antenna pair may be utilized to build an 8-element MIMO antenna by connecting four sets. Cutting slots into the system ground reduces mutual antenna coupling. The prototype of the planned antenna array has been constructed and tested. The proposed 8-element MIMO antenna has been shown to cover the 5G New Radio (NR) and WLAN 5 GHz bands n77/n78/n79 in both simulated and experimental settings. An isolation of 15 dB is available between any pair of ports. [18]

3. Research paper on "Integration of Sub-6-GHz and mm-Wave Bands with a Large Frequency Ratio for Future 5G MIMO Applications."

Sub-6 GHz and mm-wave band integration is critical for 5G wireless communications due to the large frequency ratio between the two. This research proposes a compact dual-function antenna that can work at both 3.5 GHz and 28 GHz, making it ideal for mobile 5G applications. The proposed antenna uses a microstrip patch connected to a winding radiating structure by a radio frequency PIN diode. By using a meandering line structure and a shorter ground plane, the size of the proposed antenna was drastically decreased. Long- and short-edge antenna layout for 8x8 MIMO was shown to boost functionality. Without any extra decoupling structure, the system's 10 dB bandwidths at low and high frequencies are 7.4 percent and 4.8 percent, respectively. The results from the prototypes and the simulations agreed well. Absorption rate and power density in the required frequency ranges were the basis for a safety investigation conducted using a human-like model. Consistency with safety standards was achieved. The proposed antenna system combines sub-6 GHz and mm-wave bands into a single, space-efficient design boasting a high frequency ratio and excellent multiple-input, multiple-output (MIMO) capabilities. [19]

4. Research Paper on "4 Element compact triple band MIMO antenna for sub-6 GHz 5G wireless applications."

For Sub-6 GHz 5G applications, it is expected to use a low-profile four-element MIMO antenna with a common ground plane. In spite of the common ground plane, it is shown that the current may be contained and mutual coupling reduced by using an antenna shape with slot cuts. MIMO diversity performance and isolation levels are investigated in depth. The low-profile MIMO can reach isolation levels of dB while yet maintaining a dimension of 32 mm x 32 mm. All measures of diversity are within acceptable ranges, including ECC, TARC, DG, MEG ratio, and CCL. With average efficiency and gain on the order of 89 percent and 2.5 dBi, respectively, a MIMO antenna resonating in the triple-band, directed patterns is well-suited for 5G wireless applications where space restrictions should be precisely matched. [20]

5. Research Paper “Multi-Band 10-Antenna Array for Sub-6 GHz MIMO Applications in 5G Smartphones.”

For large-scale multiple-input multiple-output (MIMO) applications in upcoming 5G devices, it is planned to use a multi-band 10-antenna array operating in the sub-6 GHz spectrum (LTE bands 42/43 and LTE band 46). Ten T-shaped coupled-fed slot antenna components that can excite dual resonant modes are incorporated onto a system circuit board to accomplish 1010 MIMO applications over all three LTE bands. These components benefit from spatial and polarization diversity approaches that enhance isolation and reduce coupling effects. An experimental array of the proposed antennas was built and measured. In both the low and high frequency ranges, the antenna efficiency was found to be over the desired threshold of 62 percent in both cases. Important metrics including the mean effective gain (MEG) ratio, channel capacity, and the envelope correlation coefficient (ECC) have also been calculated and evaluated. The 10x10 MIMO system in LTE bands 42/43 and LTE band 46 achieved ergodic channel capacities of up to 48 bps/Hz and 51.4 bps/Hz, respectively, according to the calculations. [21]

6. Research Paper on “A multi-slotted antenna for LTE/5G Sub-6 GHz wireless communication applications”

Here, we design, fabricate, and test a small multi-slot antenna for usage in LTE and sub-6 GHz 5G networks. The proposed antenna consists of a slanted rectangular radiating element with three slots and a partial ground plane, and it has a footprint on both sides of a FR4 microwave substrate. The results demonstrate that the specified antenna, which employs a multi-slotted patch that interacts efficiently with the ground plane, is capable of operating throughout the whole range of sub-6 GHz 5G bands, in addition to the 22/42/43/46 GHz WiFi, WLAN, and LTE bands. Its considerable gain and efficiency, as well as its continuous omnidirectional radiation patterns, make it an appealing alternative for the subsequent 5G networks, and it is backwards-compatible with WiMAX, WLAN, and 4G systems. [22]

7. Paper on “Design of MIMO Antenna with an Enhanced Isolation Technique”

The performance of MIMO antennas may be evaluated by looking at how well they isolate signals entering and leaving their individual microstrip patches. The patch antennas sit atop a 1.46 mm thick Rogers RO3003 substrate that measures 60 mm in length and 50 mm in width and has a relative permittivity of 3. Two coaxial probes are extended from the sub-ground layer to activate the resonators, which are spaced a mere 0.06% of a wavelength apart. High isolation (decrease in mutual coupling) is accomplished by inserting a faulty ground structure in the form of an H-slot into the layer of the ground below. The suggested MIMO antenna uses a frequency of 5.3 GHz, making it compatible with WiMAX, Wi-Fi, and even the upcoming 5G services in any part of the globe. The intended structure has been modeled using a high-frequency structure simulator based on the finite element technique (HFSS). Simulation findings reveal that at the target frequency, the reflection coefficient (S11) and isolation (S21) are -32 dB and -41 dB, respectively. [23]

8. Paper on "Wideband Flexible/Transparent Connected-Ground MIMO Antennas for Sub-6 GHz 5G and WLAN Applications"

Here we show you a transparent wideband four-element MIMO antenna with a connected ground plane that is both flexible and transparent. Transparency in light transmission is provided by both at-4 and Meliex. Using circular stub-loaded C-shaped resonators and a carefully crafted flexible Melinex substrate with an L-shaped partial ground plane, a 0.33 x 0.48 mm antenna was constructed at the lowest operating frequency. The proposed antenna features 15 dB of isolation between parts and an impedance bandwidth of 2.21-6 GHz (92.32 percent). Given its adaptable design and 4-ohm sheet impedance, a maximum gain of 0.53dBi and minimum efficiency of 41% are not unreasonable expectations. ECC and DG values for MIMO antennas are all satisfactory. When flexed in both the X and Y directions, the proposed transparent MIMO antenna displays remarkable scattering properties, radiation pattern, and MIMO diversity performance. For Internet of Things (IoT) applications where visual clutter and co-site localization are of paramount importance, the exible MIMO antenna's combination of features makes it an ideal antenna choice. [24]

9. Research Paper on "Study on Bandwidth Enhancement Techniques of Microstrip Antenna"

In this work, they created a triangular UWB microstrip antenna with an 8 GHz UWB. This antenna design maximizes UWB gain. Researchers slightly shortened the ground plane (defected ground), put slits in the triangular radiating patch, and employed alternate substrate materials to generate band-notched UWB. A tiny triangular coplanar UWB microstrip antenna was created. Coplanar-fed triangular patch with a slot and slits. The same antenna with the lousy ground causes notches in WiMAX and WLAN. The antenna has a solid average gain across all pass bands. The UWB curve rises as the substrate's dielectric constant lowers. The primary radiator is a triangular patch printed on FR4 with a dielectric constant of 4.4 and a height of 1.6 mm. According to simulations, the antenna produces 7.2 GHz UWB from 2.8 to 10 GHz with five dBi directivity and 3 dBi gain (Fig. 1). The FR4-based antenna uses a 50 coplanar feed line. According to modeling studies, adding a slot and slits to the triangular resonator boosts the upper-frequency limit to 8.3 GHz. Compared to the original antenna with a more considerable gain and directivity, the total bandwidth increased by 1.1 GHz, and the return loss (S1,1) was reduced. [25]

10. Research Paper on “A compact double-band planar printed slot antenna for sub-6 GHz 5G wireless applications.”

For sub-6 GHz 5G applications in the future, we offer a planar dual-band patch slot antenna with a rectangular slot microstrip patch feed. The antenna's performance in terms of its parameters, such as 10 dB return loss (S11 parameters), peak gain (dBi), overall efficiency, and radiation characteristics, has been studied via simulation and measurement. The measured data shows that the antenna has a peak gain of 7.17 dBi, a radiation portion of "0.3 0 0.17 0," and a profile of "0.009 0." It operates across a dual-band spectrum from 3.29 to 3.56 GHz and 4.39 to 5.2 GHz. Simulations with the dielectric back cover and the human head-hand model have proven that the antenna performs well. According to the results, the SAR value is low enough for safe use, allowing us to keep the same level of efficiency and radiation patterns we have now. This antenna may be suitable for sub-6 GHz 5G applications due to its more straightforward construction and lower manufacturing cost, including all the associated characteristics. [26]

11. Research Paper on “An Integrated Antenna System for 4G and Millimeter Wave 5G Future Handheld Devices “

In this study, we describe a Defected Ground Structure (DGS) integrated antenna system for use in 4G and 5G wireless applications and portable devices operating at millimeter waves. The suggested layout is predicated on a 110 mm × 75 mm Rogers RT/Duroid 5880 substrate with a thickness of 0.508 mm. The development of fifth-generation wireless networks for mobile and broadband wireless communication has been accelerated by researchers. In recent years, millimeter-wave radios have become a viable option for 5G low-latency, multi-Gbps wireless networks. The 4G antenna array supports the two sub-6 GHz frequency bands with their respective centers at 3.8 GHz and 5.5 GHz and measured bandwidths of 160 MHz and 450 MHz. In contrast, the 5G antenna array makes use of a 4.9 GHz bandwidth to support mm-wave frequencies in the 26/28 GHz range. [27]

12. Research Paper on “A Flexible Directional Antenna for 5G Millimeter-wave Applications”

This paper proposes a new flexible antenna. The antenna is a microstrip antenna printed on the Rogers 5880 substrate with dimensions of 12.25mm×7.45mm×0.07mm. The simulated bandwidth is 24.6-24.7GHz. The antenna has a directional pattern with a maximum gain of 6.16dBi. The purpose of this paper is to design a flexible antenna with a direction pattern working at 24 GHz. The configuration of the proposed antenna is a rectangular patch antenna fed by a 50 Ω microstrip line to obtain a directional pattern. Step shape feeding lines and slots etched on the patch are adopted to enhance antenna bandwidth. The antenna substrate is of Rogers 5880 substrate with a relative dielectric constant of 2.2 and thickness of 70 µm. [28]

13. Research Paper on “Ultra-wideband Microstrip Array Antenna for 5G Millimeter-wave Applications”

This research presents a stepped line cut and U-slot hybrid design for a 5G millimeter-wave ultra-wideband microstrip array antenna. The suggested layout uses a feeding mechanism based on proximity coupling to improve bandwidth performance. The bandwidth increase may be calculated by comparing the proposed antenna's bandwidth performance to that of a conventional antenna array design. The numerical and simulated findings show a significant improvement in bandwidth performance compared to the conventional design. The proposed antenna operates within a 28 GHz range, has a 4.47 GHz bandwidth, and a gain of 8.71 dB. These results validate the viability of the suggested antenna design for millimeter-wave 5G technology. Microstrip antennas for 5G millimeter-wave usage were designed using a combination of U-slot and stepped line cut methods to improve bandwidth and gain performance. A slot antenna may be created with the use of a stepped line cut method. The slot antenna's value lies in the fact that it can generate directional radiation patterns across a wider frequency range. Since the Q factor is inversely proportional to the bandwidth of an antenna, the presence of slots in the antenna might cause a coupling effect that decreases the Q factor. [29]

14. Research Paper on “Compact and Wide Bandwidth Microstrip Patch Antenna for 5G Millimeter Wave Technology: Design and Analysis”

According to this research, fifth-generation (5G) technology will focus on improving fourth-generation (4G) systems, addressing issues including 4G's sluggish bandwidth and data transfer rate. Fifth-generation wireless networks will facilitate the digitization of the economy ushering in the Fourth Industrial Revolution. In order to do so, we need 5G networks with a lot of storage space. A microstrip patch antenna is used for 5G mmWave communications. Gain, radiation pattern uniformity, size, and frequency response have all been improved upon in a microstrip patch antenna operating at 28 GHz (mm-wave). With a dielectric constant of 4.3, a thickness of 1.6 mm, and a loss tangent of 0.025, the FR-4 substrate used in this study was ideal for this investigation. The ideal antenna has a high directivity of 7.465 dBi and a reflection coefficient of -40.14 dB. It also has a VSWR of 1.1098 dB, a maximum gain of 5.29 dB, and a VSWR of 1.1098 dB. The device has a bandwidth of 14.674 GHz. The study's antennas, notably those operating at 28 GHz, achieved the greater gain and wider bandwidth necessary for 5G applications. The antenna's adaptability is shown by its wide frequency range of 14.674 GHz (from 21.227 to 35.874 GHz). The gain was 5.29 decibels, and the directivity was 7.465 decibels, for a total bandwidth of 52.4%. In terms of bandwidth performance, the antenna was adequate for broadband applications and could send high-quality data. Overall, the suggested antenna was able to achieve an efficiency of 60.6%. [30]

15. Research Paper on “Highly Efficient 2x2 Antenna Array at 28 GHz and 38

GHz for 5G Applications”

More than 100 billion wireless devices may be connected using 5G technology, with latency measured in milliseconds and data speed of 10 Gbps. An authoritative source predicts that by 2021, most countries will have deployed 5G. The purpose of this work is to create a 2x2 antenna array operating at 28 and 38 GHz, which is required by 5G standards. The results showed that the antennae were not up to par with 5G specifications. In this study, 2x2 antenna arrays operating at 28GHz and 38GHz were built. Foam substrates with a Hs = 0.5mm height and quarter-wave feeding are used in both antenna designs. The antenna has a VSWR of 1.001, a gain of 15.4 dB, a bandwidth of 61.19 GHz, and an efficiency of 97.97% at 28 GHz and 52.28 GHz, 13.8, 1.005, and 97.97%, respectively. There were no gaps in coverage that the suggested antenna array didn't fill better than the previous attempt. The bandwidth of the antenna array is 1.3 and 2.54 GHz at 28 and 38 GHz, respectively. Gains of 15.3 dB at 28 GHz and 13.6 dB at 38 GHz are achieved using the antenna array.[31]

16. Research Paper on “Optimization of Design Parameters of Microstrip Patch Antenna at 28 GHz and 38 GHz for 5G Application”.

The challenging nature of 5G antenna design sparked this idea. Designers of 5G antennas at 28 GHz and 38 GHz have a hard time meeting specification. The literature is discussed in the next section. For 38 GHz, the return loss and gain of a single-element MPA are 15.5 and 6.9 dB, respectively; for 54 GHz, they are -12 and 7.4 dB. The antenna's inefficiency was shown by a return loss of around -10dB. Multi-band aggregator (MPA) that can support three frequencies, including 5G. This antenna had a frequency range of 900 MHz at 28 GHz and 480 MHz at 38 GHz. 7.02dB gain at 28 GHz and 5.05dB at 38 GHz. 5G channel bandwidth is 1 GHz. Hence, it's difficult to cover such a large bandwidth. The increase is below 5G standards. The multiband MPA contains 5.5 GHz at 37 GHz and 8.67 GHz at 54 GHz. This antenna's higher bandwidth is a waste of operating frequency since it uses more battery power than a genuine 5G antenna. Gains of 5.5dB at 37 GHz and 6dB at 54 GHz do not meet 5G requirements. Air is the substrate for a high-gain single-element antenna. Despite meeting 5G standards, this antenna is constructed on a difficult air substrate. Antenna performance depends on substrate element, height, and feeding method. If chosen incorrectly, 5G criteria won't be satisfied. This study determined the best substrate element, substrate height, and feeding method for 5G-compliant 28-GHz and 38-GHz MPAs. Using these three design parameter values, antenna performance is compared. [32]

17. Research Paper on “Analytical Review of Bandwidth Enhancement Techniques of Microstrip Patch Antenna”

Bandwidth is a concern. Antenna designers are constructing compact broadband antennas. In the last decade, literal analysis was used to increase the MPA's capacity. The slot method, air gap technique, multiple radiating element technique, parasitic patch technique, multiple feeding technique, and proximity couple technique are compared in this research. Wireless data speeds need broadband antennas. 5G wireless communication employs a greater bandwidth spectrum. Antenna designers are designing small broadband antennas. The MPA's tiny size, low profile, cheap cost, and durability attracted the designer. Single resonance radiation limits microstrip patch antenna bandwidth. Microstrip patch antennas have less than 5% bandwidth. Slot antenna efficiency and directivity decrease as the number of slots increases. [33]

18. Writing on the topic of "Design of 2x2 Microstrip Patch Antenna Array at 28 GHz for Millimeter Wave Communication," this document is a study of the topic.

The shortcomings of 4G in terms of capacity, latency, and route loss have necessitated the development of 5G wireless technology. Overcoming the limitations of 4G, 5G wireless technology offers millisecond latency, 10 Gbps data rates, and the ability to communicate with 100 billion wireless devices. Making a 2x2 antenna array that works well for 5G is the focus of this research. The primary objective is to build a functional antenna array. One patch antenna's planned feed line is seen in the front of the image. [34]

19. Writing on the topic of "Design and Analysis of a 28 GHz Microstrip Patch Antenna for 5G Communication Systems"

In this study, we present the methodology used to create a microstrip patch antenna (MSPA) that can function at 28 GHz for 5G wireless networks. We may deduce the following specifications from these values: 1.046 GHz bandwidth, 7.587 dBi beam gain, 7.509 dBi directivity, and 98.14% radiation efficiency. With a loss tangent of 0.0025, a r of 4.4, and a radiating copper metal thickness of 0.035 mm, the MPSA at

28GHz is constructed on a FR-4 substrate. These are the specs because of how it was designed. The bandwidth, VSWR, return loss, gain, and radiation efficiency of the MSPA are as follows: 1.046 GHz, 1.023, -38.86 dB, 7.587 dBi, and 98.214 percent. To do this, we optimized antenna dimensions, applied inset-feed impedance matching methods, and used quarter-wavelength impedance transformers. [35]

20. Research Paper on “A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications”

Antenna gain of 6.63 dB with an efficiency of 70.18 percent and a return loss of -13.48 dB are some of the recommended specs for the proposed antenna. An inset feed transmission line method is used to provide a good match between the radiating patch and the 50 microstrip feedline. When the mobile industry fully adopts the millimeter-wave spectrum, carriers are expected to use the newly available 28, 38, and 73 GHz, bands.[36]

21. Academic Paper Examining “Microstrip Patch Antennas with Multiple Parasitic Patches and Shorting Vias for Bandwidth Enhancement”

Two novel microstrip patch antenna designs, with multiple parasitic patches and shorting vias, have been suggested to expand the system's bandwidth. Broaden the antenna's reception range by adding parasitic patches to the standard triangular patch antenna to generate two additional resonances. Additionally, an antenna with a measured 10-dB impedance bandwidth of 17.4 percent from 5.5 to 6.55 GHz was constructed and evaluated. At its core, this study is concerned with the construction of a novel microstrip patch antenna, which makes use of a number of parasitic patches in order to generate three resonances. The suggested antenna's bandwidth may be further increased by including parasitic patches into its design, which allows for the creation of two additional resonances. Parametric studies have been carried out to examine the effect that the antenna's dimensions have on its overall performance. Then, two shorting vias are added to the aforementioned antenna to lower the input impedance at certain frequencies, increasing the bandwidth. To verify the validity of the design ideas, two prototypes of the proposed antennas were built and tested. The measured data shows that the impedance bandwidths of these two antennas at |S11| 0 dB are 13.8% wider at 5.46 GHz compared to 17.4% wider at 6.27 GHz. They can both produce a very respectable far field. [37]

3.2 Summary

Multiple-input multiple-output (MIMO) technology turns space, along with time and frequency, into a resource that improves wireless communication performance. With the ideas and applications for distributed antennas, massive MIMO, and 3D MIMO technologies, the demand for spatial channel modeling is constantly increasing. The coupling relationship between location, time, and frequency is critical for wireless communication system performance. Altering the antenna's design parameters to achieve a higher bandwidth in preparation for 5G uses.

Multiple-input, multiple-output (MIMO) may send and receive data from several sources simultaneously. This aids in reducing congestion and boosting transfer rates. These are the reasons that most motivated me to work in the field of MIMO antenna. Undoubtedly, the MIMO antenna will work better in the future. As of now, a lot of mobile operator companies are getting rid of the massive cell. Cellular communication is exceptionally diverting in the era of 5G communication. We are going to follow the path. We are going to design a MIMO antenna that will have the best performance compared to some other MIMO antennae.

3.3 Objectives

- ✓ To improve bandwidth for 5G uses, a single microstrip patch antenna was built and modeled.
- ✓ Altering the antenna's design parameters to achieve a higher bandwidth in preparation for 5G uses.
- ✓ Antenna design for 5G uses a variety of parameters, including insertion gap, patch width, patch length, and so on, to achieve optimal performance.
- ✓ At last, choose the best antenna.
- ✓ The goal of this project is to design and develop a microstrip patch antenna with optimized antenna characteristics, most notably increased bandwidth, for use in 5G networks.
- ✓ To improve the microstrip patch antenna performance
- ✓ In order to evaluate against the current crop of 28 GHz microstrip patch antennas.

Chapter 4

Methodology

4.1 Methodology

Methodology refers to the systematic, theoretical examination of the practices common to a particular discipline. An in-depth theoretical analysis of a corpus of theories, paradigms, and techniques essential to a specific academic field. Standardization, theoretical models, stages, and quantitative and qualitative methods of study are all part of this [41]. Simply said, a methodology is a set of processes or procedures used to achieve a specific goal. Standard practices in an industry or field of study, such as the methods utilized in an investigation, might be referred to by this expression. However, a methodology differs from a technique in that it is not aimed at solving a problem. On the other hand, a methodology focuses on theoretical reinforcement to figure out what approach or set of methods may be implemented.

4.2 Research Design

The design of the study is the plan developed to address the research questions. The method of a research activity includes outlining the study topic, dependent and independent variables, experimental design, and, if applicable, data collecting techniques and a statistical analysis strategy. Specifically, this investigation used

- An analysis of the development of 5G mMIMO.
- The need for antenna research for 5G mMIMO.
- The sub-6 GHz band is my selection.
- Microstrip antennas and 5G antennas now in use should be researched in depth.
- The process of creating a microstrip antenna requires research.
- If you want to learn how to design antennas, the CST Microwave Studio is the place to go.
- Determine the antenna construction specifications.
- Identify the optimal values for the insertion gap, patch length, patch width, and other factors.
- Identify the best layout for high-throughput 5G uses.
- Choose a strategy for providing nourishment.
- Put the plan into action.

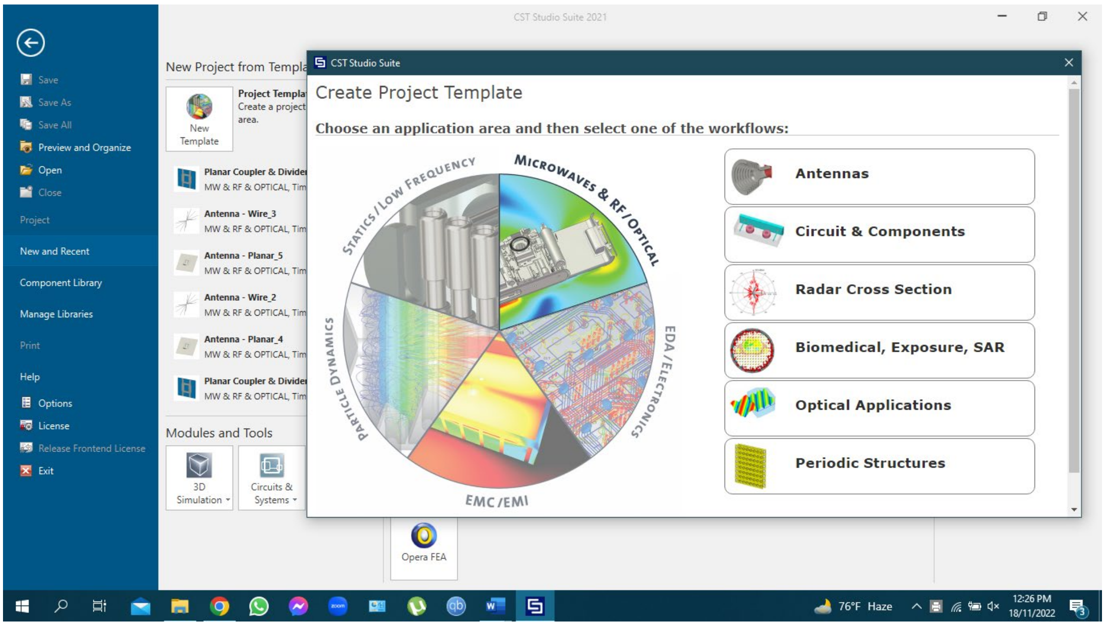
4.3 Pilot Study

Pilot studies, sometimes called pilot projects, pilot tests, and pilot experiments, are often conducted before more comprehensive research is done in order to assess feasibility, time, cost, and negative occurrences and to refine the study design. This work was done in advance of the actual study. Depending on the goals of the investigation, a pilot study may be conducted. Even though a pilot study can't prevent all systemic mistakes or unforeseen issues from happening during the primary research, it has the potential to reduce the frequency with which such mistakes occur.
The Importance of Test Runs:
In order to test the study's method and/or procedures.

- Sorting out significant factors and deciding how to put them to use.
- The team is working on this to develop or evaluate new research tools and techniques.
- In order to evaluate statistical considerations for the following studies.

4.4 Software

As can be seen in Figure 4.1, CST MWS is a powerful tool for modeling high-frequency components in three dimensions. Filters, couplers, antennas, single and multi-layer structures, and the effects of SI and EMC may all be analyzed rapidly and precisely using CST MWS. As can be seen in Figure 4.1, CST MWS is an efficient method for modeling high-frequency components in three dimensions. Filters, couplers, antennas, single and multi-layer structures, and the effects of SI and EMC may all be quickly and accurately analyzed using CST MWS. The unrivaled functionality of CST MWS has made it the preferred option for cutting-edge R&D facilities. Using CST MWS is a quick and easy way to learn about electromagnetic (EM) behavior in high-frequency systems. [42].



Choose an application area and then select one of the workflows:

Figure 4;1: Starting view of CST studio suite application

4.5 Design procedure

Step 1: Create a single-element antenna that can be used in 5G massively multiple input multiple output (mMIMO) systems operating at frequencies below 6 GHz.

Step 2: Second, the optimal dimension is determined by considering a variety of them in light of the 5G mMIMO requirement.

Step 3: Now, use a feeding technique to find a good result based on the 5G mMIMO requirement.

Step 4: Antennas for 5G mMIMO usage are designed using a substrate material, a substrate height, and a feeding mechanism with varying dimensions.

Step 5: Make a copy of the framework and run a simulation of the antenna you've built.

Step 6: Whenever the antenna satisfies the requirements, the result is saved.

Step 7; If the result is not good, then optimize the design.

Step 7: Enhance the effectiveness of the Microstrip patch antenna design you've created.

Step 8: Evaluate the outcome in comparison to the antennas currently in use.

❖ Figure 4.2 shows a research work flow diagram.

4.5.1 Antenna Substrate

Choosing a dielectric substrate with the proper thickness is the first step in antenna design (h). Dielectrics improve electrical and mechanical dependability. They help generate displacement current, which results in a time-varying magnetic field (as per Ampere's Law), and minimize the antenna's total footprint. According to Faraday's rule, this time-varying magnetic field may generate an electric field that also changes over time, leading to a wave of electromagnetic radiation. Adding a substrate to the antenna might improve its radiative efficiency.

Table 4.1 lists some typical dielectric substrates along with their features.

TABLE 4.1: LIST OF SUBSTRATES

Dielectric Material Name	Dielectric constant
FR-4	4.43
RT Duroid-6002	2.942
RO4730	3
Rogers RO 3200	3.03
Rogers RT Duroid-5880	2.21
Rogers RT Duroid-5870	2.34
Foam	1
TLC-32	4.2
Nylon	3.45
Teflon	2.14

The high dielectric constants of the substrates shown in the above table portend significant losses when designing high-gain antennas. To begin, we arbitrarily selected Rogers RT-5880 as our substrate material because of its convenient availability and high dielectric constant (2.2), both of which are useful in MPA designs. The next step is to settle on a microstrip line and ground material. Now, we may choose between copper, silver, and gold. Silver's conductivity is the highest among the metals. Conversely, copper is both more rigid and cheaper than the other two metals often used in construction. Therefore, copper is widely used.

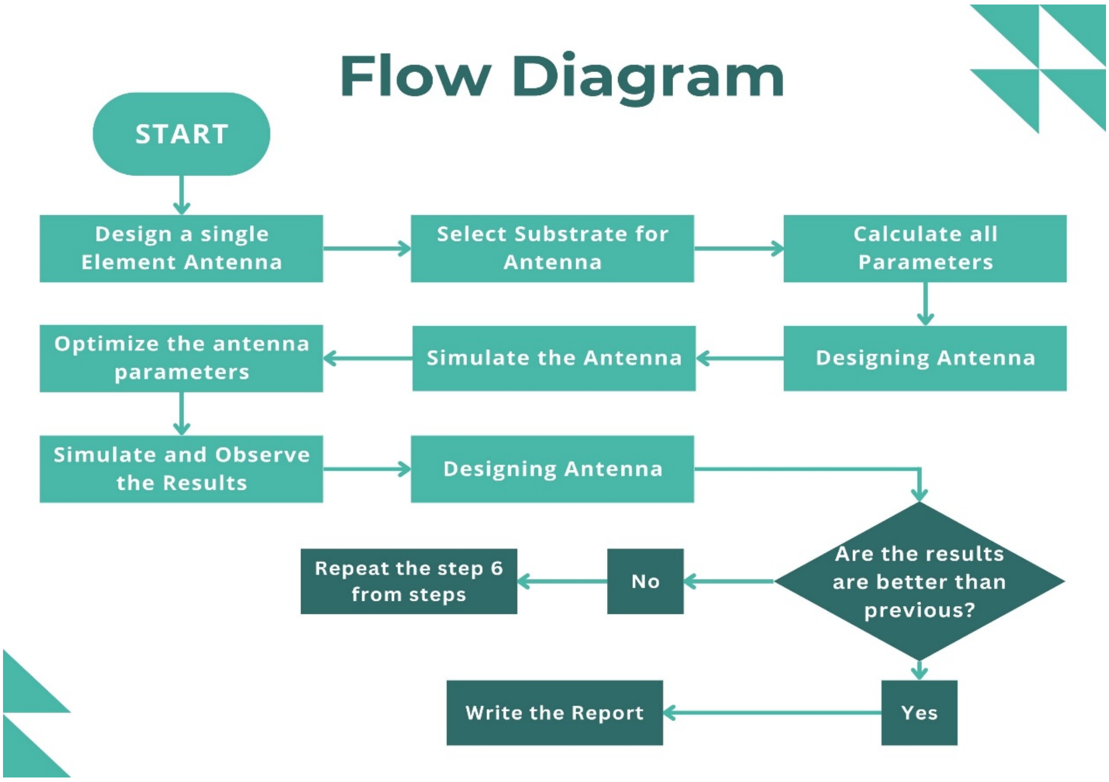


Figure 4.2: An Overview of the Research Process in a Flowchart

4.6 Formulation of Antennas

The following discussion of antenna design techniques is partitioned into many smaller parts. To get things off, this episode is focused on determining how big a "radiating patch" an antenna really has. r, Hs, and fr must all be considered while designing the radiating patch of this antenna. [43]. Second, plans for food provisioning have been made. This antenna uses a combination of inset feeding and quarter-wave transformer feeding. In the end, the decision to use a quarter-wave transformer for feeding was made.

4.6.1 Radiating patch

1. For a radiator to work well and achieve the required resonance frequency, the width design is critical. As a result, the width may be calculated using the following formula.(1).

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \text{------------------------------------} (1)$$

Where,

- ➢ Light's speed across empty space is denoted by the symbol c.
- ➢ The operating frequency, denoted by fr, is at a resonant level.

- $\in r$ is the dielectric constant of the substrate.

2. In order to determine L's true length, it is necessary to determine both the effective dielectric constant and the length extension. The effective dielectric constant may be roughly estimated by plugging some values into the following equation: (2).

$$\epsilon_{eff}=\frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\left(1+\frac{10Hs}{w}\right)\text{----------------------}(2)$$

Where,

- The substrate height is denoted by Hs.
- Patch width, denoted by w,

3. In the second place, the equation below is used to determine the lengthening (3).

$$\Delta L=0.412\,h\frac{c(\varepsilon reff+0.3)(WHs+0.264)}{(\varepsilon reff-0.258)(WHs+0.8)}\text{-----------------}(3)$$

4. Finally, the value of L is calculated using the following equation (4).

$$L_{eff}=\frac{c}{2f_r\sqrt{\epsilon_{eff}}}\text{------------------------------}(4)$$

4.6.2 Feed-line

1. Before anything else, a microstrip inset feed is required to impedance-match the radiating patch inset. Figure 3 depicts a possible layout for a hypothetical inset feed line. Formula for determining inset feed position: (5).

$$xo=\frac{L}{\pi}\cos-1\sqrt{\frac{Zo}{Z1}}\text{----------------------------}(5)$$

Where,

- Zo=50 Ω is the transmission line impedance. ➢ Z1 is the characteristic impedance.

The characteristic impedance Z1 is calculated by below equation (6).

$$Zin=\sqrt{Zo*Z1}\text{----------------------------}(6)$$

Where,

- According to [49], the calculator's input impedance, Zin, is defined as follows: Additionally, Feed width wf and feed length Lf are two additional specifications for the inset feed. Below, we provide the formulas (7) and (8) needed to determine such values.

$$Wf=\frac{2Hs}{\pi}\{B-1-\ln(2B-1)+\frac{\varepsilon r-1}{2\varepsilon r}[\ln(B-1)+0.39-\left(\frac{0.61}{\varepsilon r}\right)]\}---------(7)$$

$$Lf=3.96*Wf-------------------------------(8)$$

Where,

$$B=\frac{377\pi}{2Zo\sqrt{\epsilon_r}}-------------------------------(9)$$

2. Second, the quarter-wave transformer feeding method is used when impedance matching becomes difficult. Figure 3.3 depicts the feed line for a quarter-wave transformer. It is essential that the impedance of the feed line and the breadth of the radiating patch match in this case. To compensate for the impedance of the 50-ohm transmission line, a second feedline with a variable width is linked to the first. The widths of the first and final feedline segments may be calculated with the help of the following formula (Wf2):

$$Wf1=Wf2=\left(\frac{377}{Zo\sqrt{\epsilon_r}}-2\right)*Hs----------------------(9)$$

Where,

- ϵr= Dielectric constant of the substrate element
- Zo= impedance of the feed line

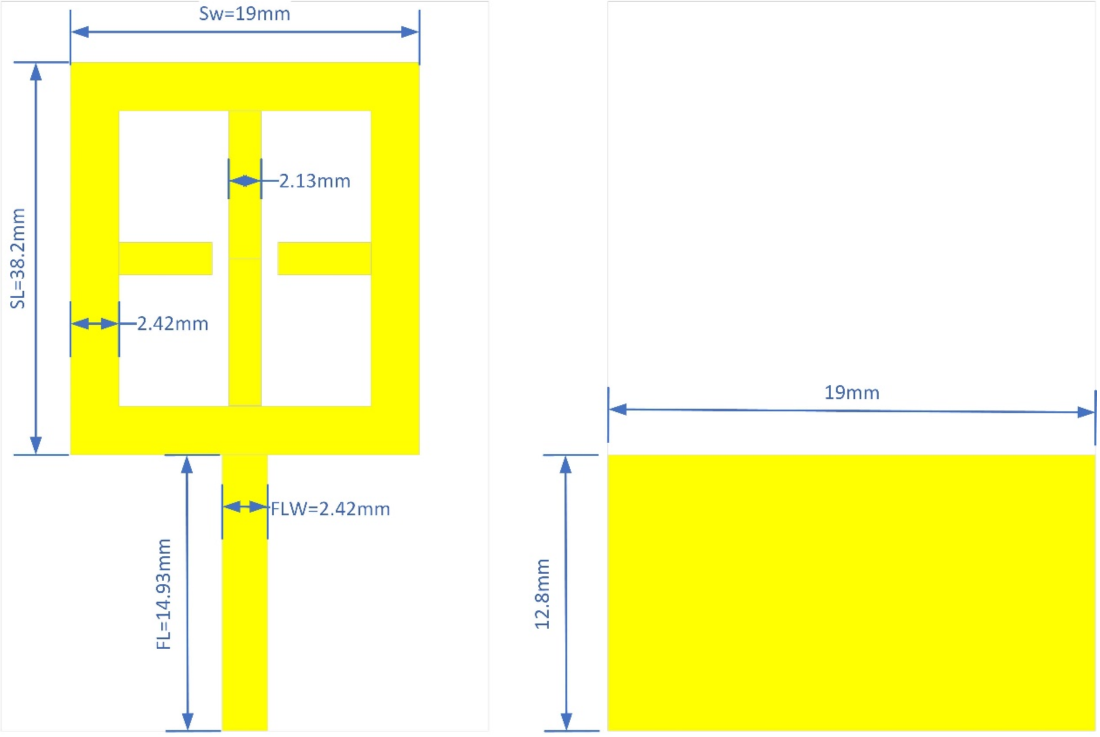
Finally, an MPA that satisfies all 5G requirements may be generated utilizing the aforementioned nine formulae. The estimated antenna parameters will then be used in the antenna design by CST microwave studio.

4.7 Geometry and antenna design parameters

To describe antenna design in accordance with the above concept, three criteria have been developed. Substrate elements, height, and feeding technique are all factors to consider. The section below shows the antenna geometry for several design options.

4.7.1 Size-variant antennas

First, decide on a dielectric substance to serve as the antenna's substrate. The constructed antenna will perform better if various parameters are calculated with extremely excellent dimensions. As can be observed in Figures 4.3 and 4.4, the patch and ground plane of this proposed antenna are made of copper conductor material and installed on a FR-4 substrate.



Front View

Back View

Figure 4.4: Front and Back view of the Antenna

Table 3.1 displays the results of applying the equations presented in the antenna technique section to the problem of building an antenna for Sub-6 GHz. The height of the substrate, Hs = 0.5mm, was chosen. According to the findings, this value for the parameter could shift in the near future.

Table 4.2: The parameters of the antenna's design are optimized for operation at frequencies lower than 6 GHz.

Antenna Parameters		
Sw	19	Substrate Width
Sl	38.2	Substrate Length
Sh	1.6	Substrate Height
Flw	2.42	Feedline Width
Fl	14.93	Feedline Length
t	0.035	Patch Thickness
Bew	17.17	Bottom Element Width
Bel	2.13	Bottom Element Length
Rew	2.13	Right Element Width
Rel	17.87	Right Element Length
Lew	2.13	Left Element Width
Lel	17.87	Left Element Length
Tew	17.17	Top Element Width
Tel	2.13	Top Element Length
Gw	19	Gap Width
Gl	12.8	Gap Length
Cew	1.07	Center Element Width
Cel	9.57	Center Element Length

Chapter 5

Results Analysis and Simulation

In this section, we describe and discuss the results of running a simulation of the planned antenna.

5.1 The Outcomes of Antenna Modeling Simulations

Different Parameters of antennas over a variety of scales are the subject of study and discussion here. The criteria outlined in this book were all put to use in this investigation. The final antenna's parameters are settled upon by comparing the characteristics of the completed antenna with those of the original antenna design.

5.1.1 Examination of the Conceived Antenna's Outcomes

The result of our antenna perfectly matches with [3]. After simulating the antenna, we get a return loss of 33 dB. The operating frequency of the antenna is 2.6 GHz. Though after tweaking the parameter, we get another band at 5 GHz, which gives us a return loss of 23 dB. The efficiency of the antenna is 87% at 2.6 GHz. The voltage standing wave ratio is between 1 to 2. The most exciting result of our antenna is we get a perfect omnidirectional radiation pattern which is pretty challenging to achieve. The novelty of our antenna is 100%, and we aim to do a 4-element MIMO with this antenna to achieve the objective of our research.

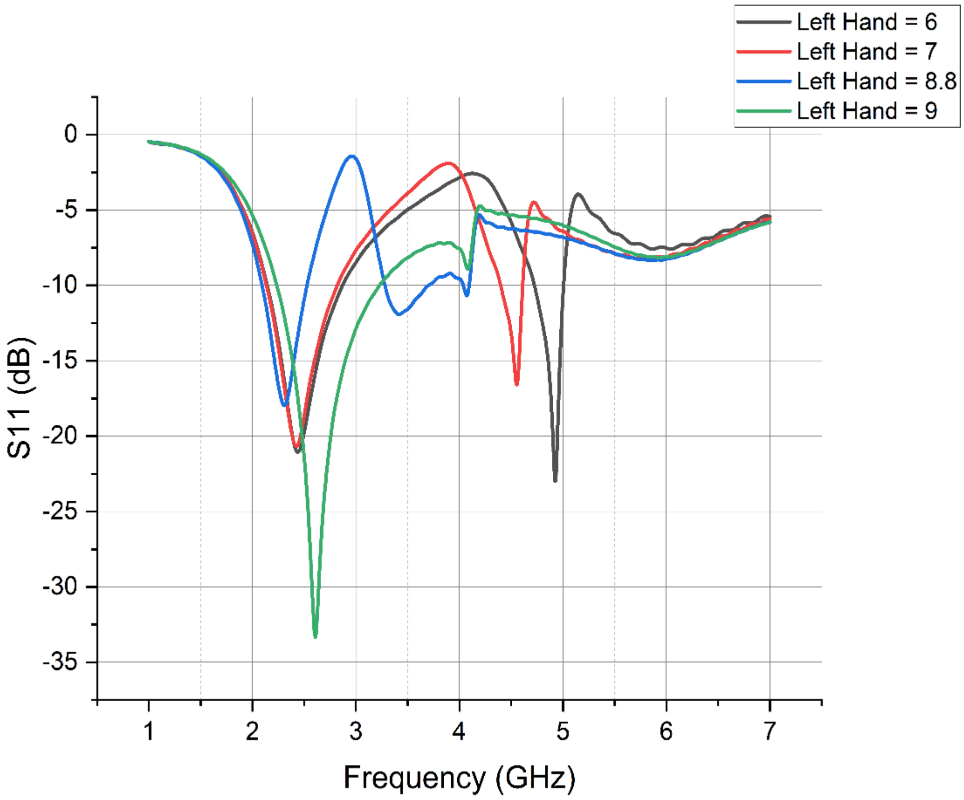


Figure 5.1: S11 value of the proposed antenna with a left-hand tweak

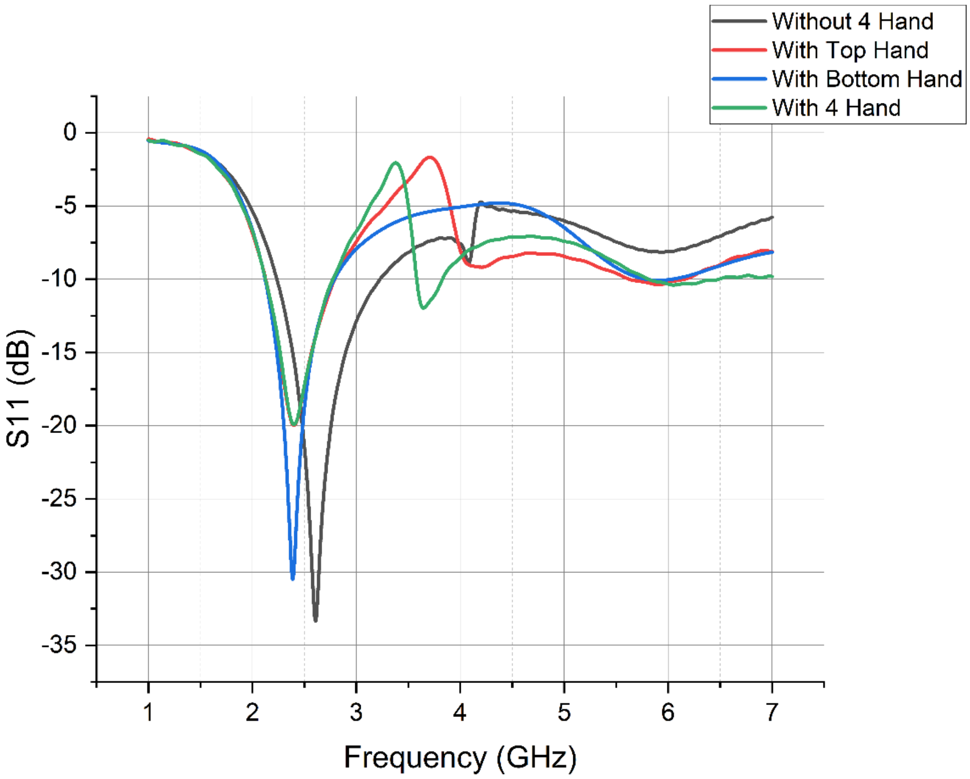


Figure 5.1: S11 value of the proposed antenna with a different tweak

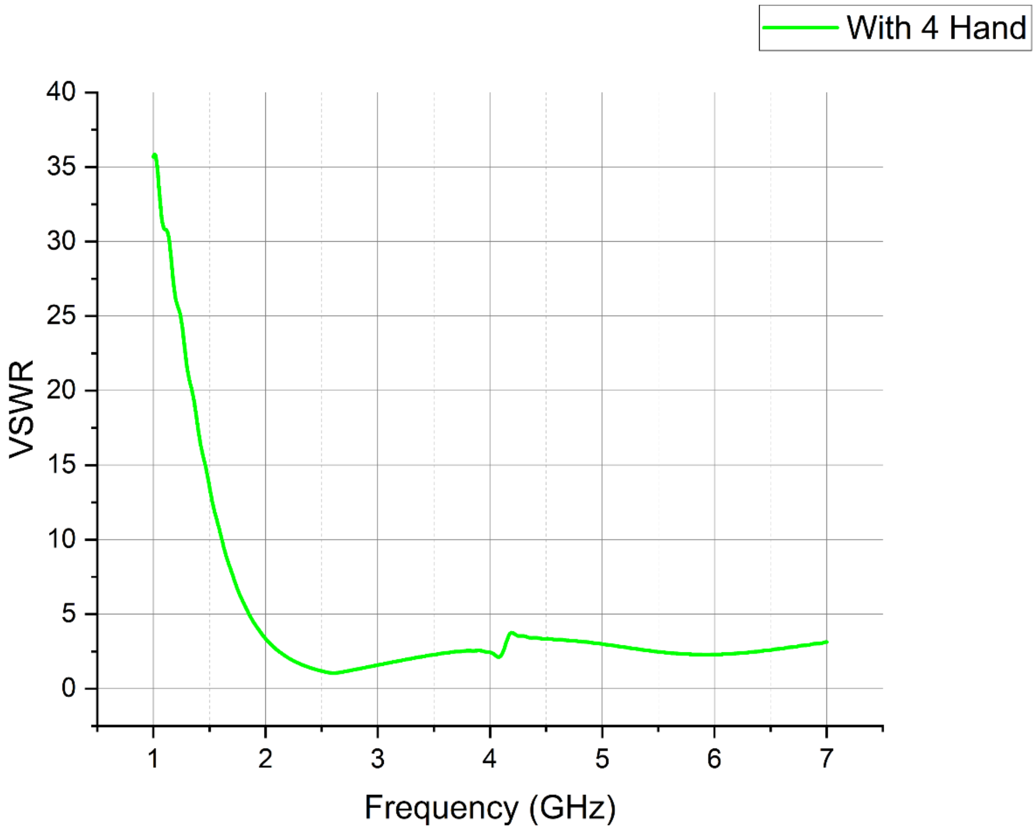


Figure 5.2: VSWR of the proposed antenna

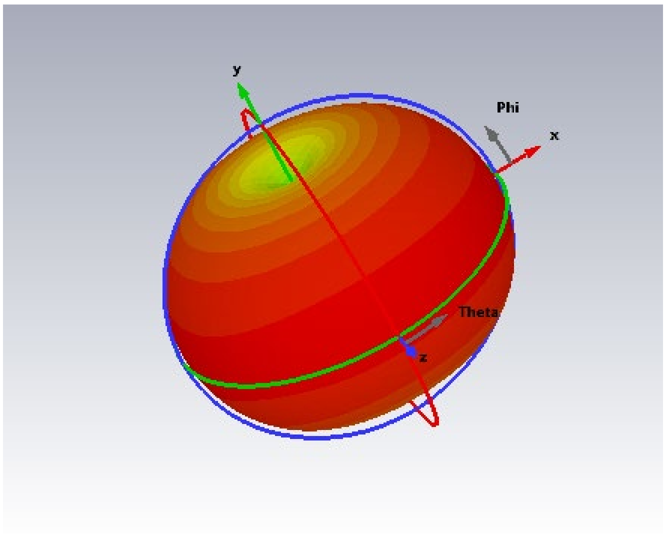


Figure 5.4: The proposed antenna's 3D radiation pattern at 2.5 GHz

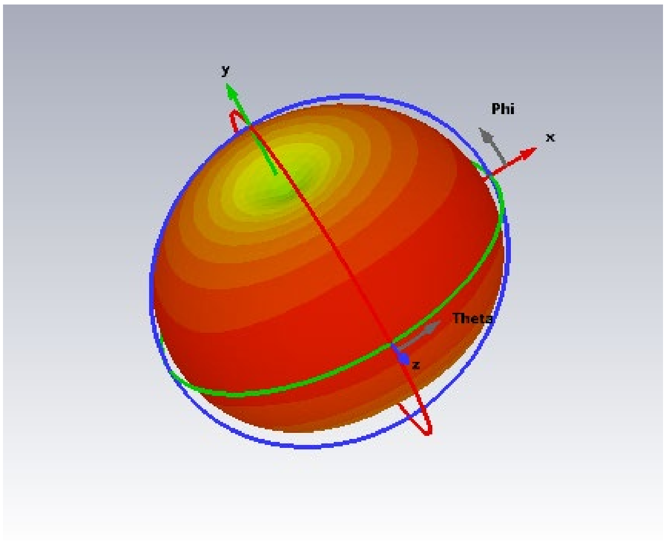


Figure 5.4: The proposed antenna's 3D radiation pattern at 3.5 GHz

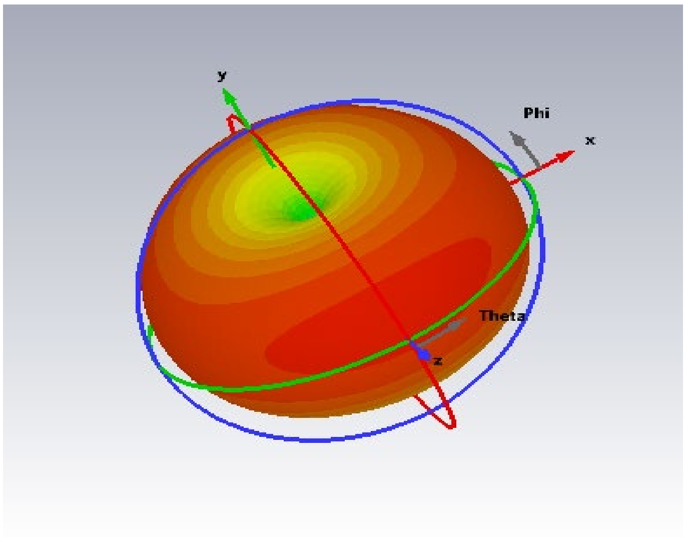


Figure 5.5: The proposed antenna's 3D radiation pattern at 4.5 GHz

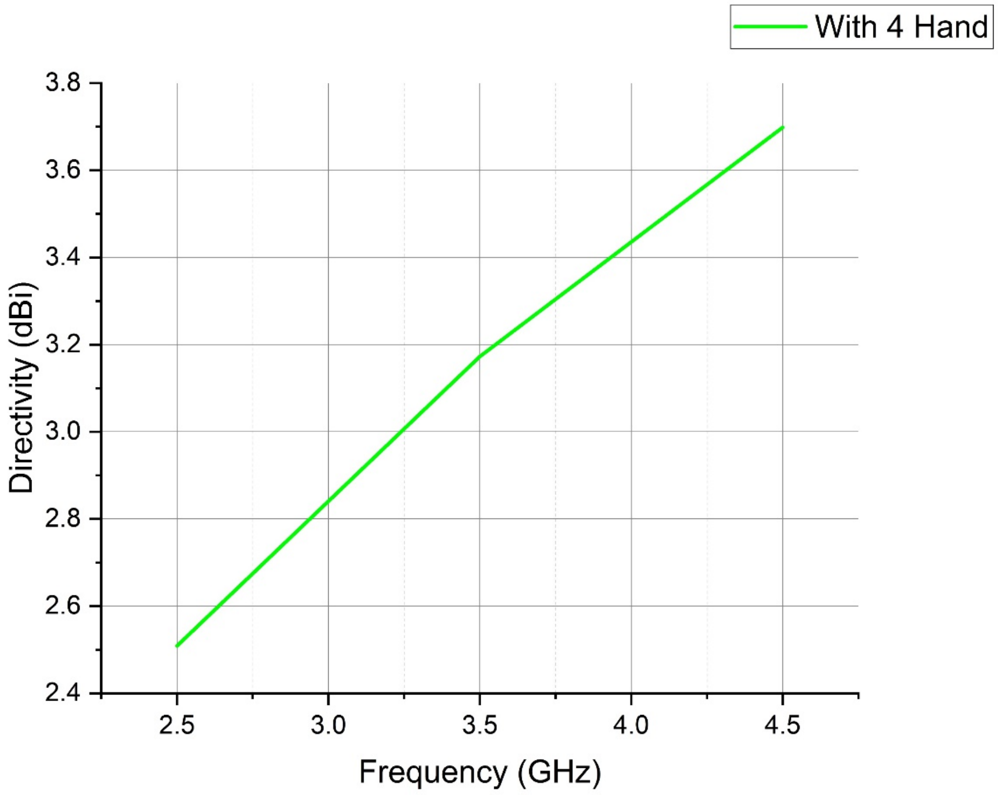


Figure 5.6: Directivity of the proposed antenna

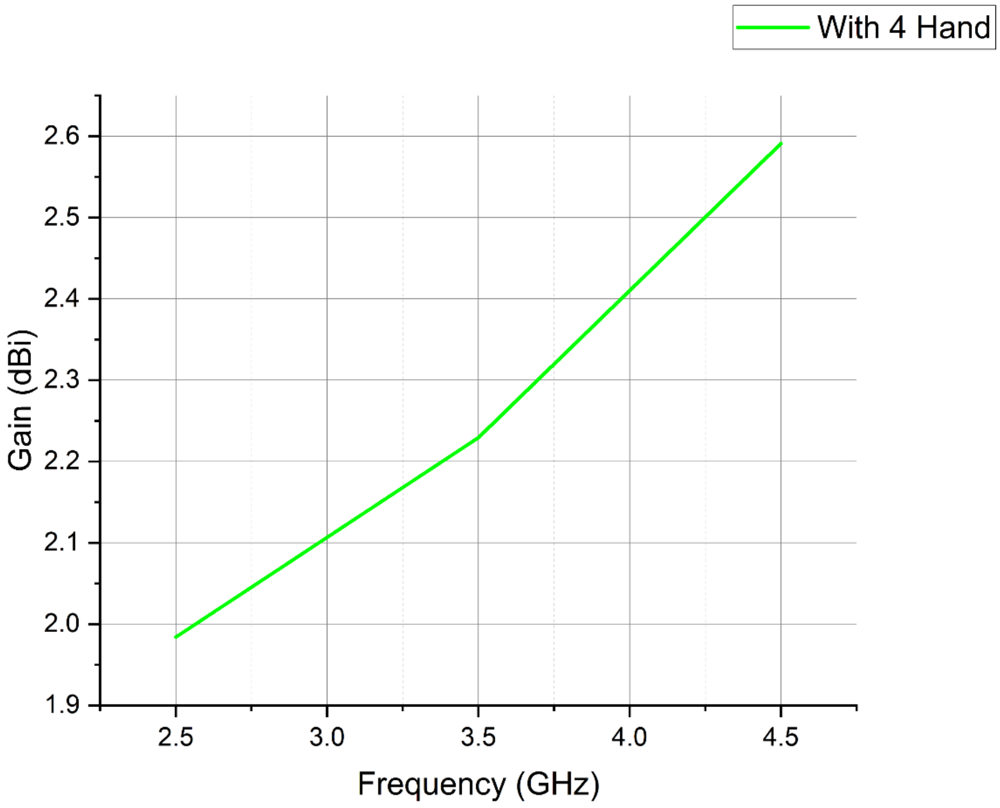


Figure 5.7: Gain of the proposed antenna

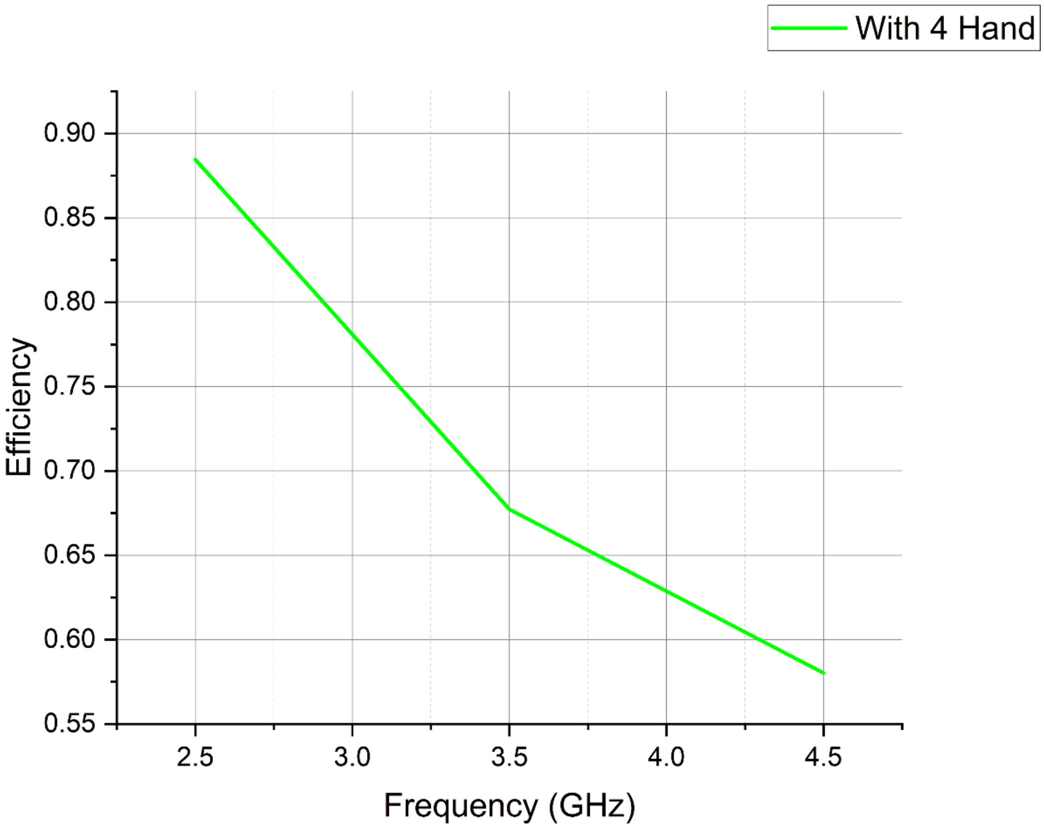


Figure 5.8: Efficiency with regards to the planned antenna

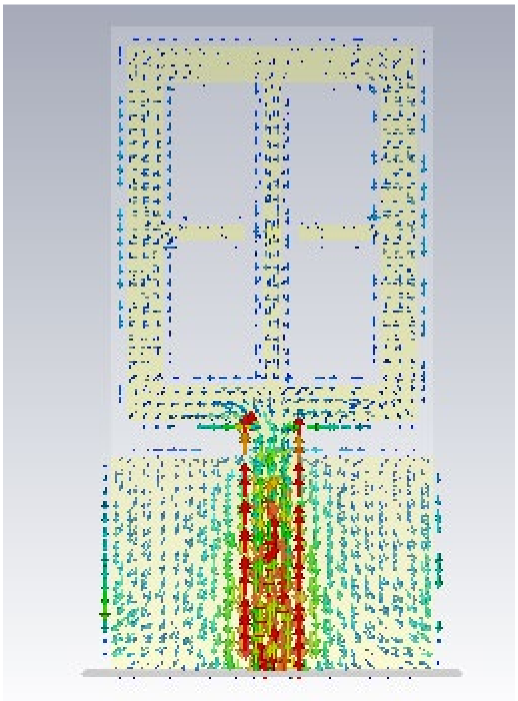


Figure 5.9: Surface current of the proposed antenna at 2.5 GHz

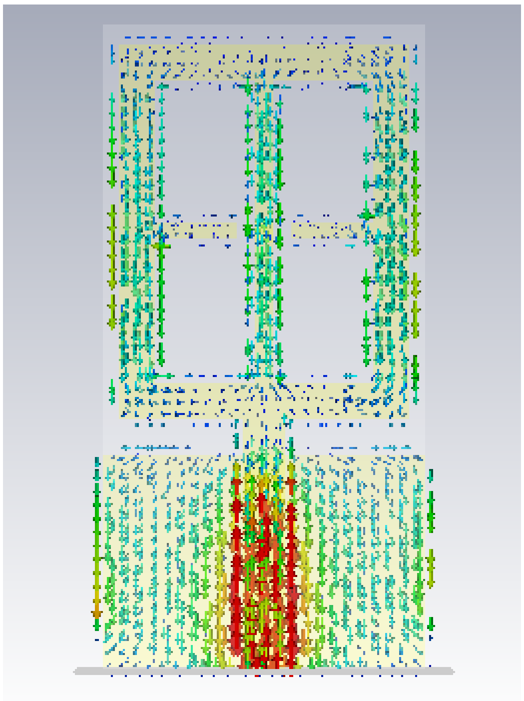


Figure 5.10: Surface current of the proposed antenna at 3.5 GHz

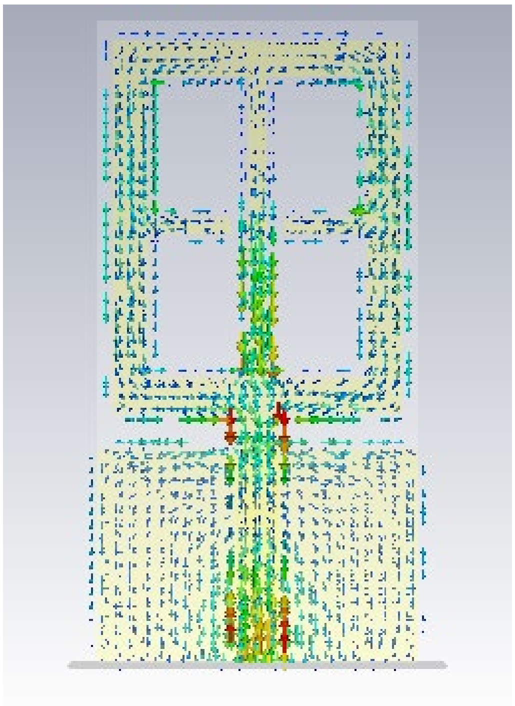


Figure 5.11: Surface current of the proposed antenna at 4.5 GHz

Table 5.1: Results from antenna parameter simulations at a frequency of 28 GHz

Antenna Parameter	Results/Outputs
Return Loss, S1,1	-33.45 dB
Bandwidth	Multiband
Gain	2.6 dBi
Directivity	3.7 dBi
VSWR	1.054
Efficiency	88%

5.2 When compared to the standard antenna consisting of only one element

Tables 4.4 and 4.5 below compare the proposed study to previous studies. These head-to-head tests demonstrate that the suggested antenna, which was developed using flexible sizing parameters, better meets the requirements of 5G networks than did the prior studies.

Table 5.2: The present single
element antenna is compared to new designs over a range of frequencies.

Refs.	**Year**	**Operating band (GHz)**	**Total size (mm^3)**	**Gain (dBi)**
[7]³	2020	1.6-5.5 (-6 dB)	135x80x0.8	-1.3 ~ 4.7
[8]³	2020	3.28-3.78	180x60x1.6	2.4 ~ 6.1
[9]	2019	3.05-4.42	150 x 150 21	7.09 ~ 9.36
[10]³	2020	3.34-5.0(-6dB)	150 x 80 x 0.035	4.25 ~ 6.0
[11]	2019	2.5-4.8 (-6dB)	129.75 x 50 x 0.8	1.8 ~ 2.9
[12]	2019	2.32-5.24	80x50x0.508	3.04 ~ 4.31
[13]³	2019	3.39-3.62	100x100x5.7	5 -6.8
[15]	2020	1.341-3.834	76 <42x16	1~3.2
[16]	2021	2.84-5.17	63x51.2x4.5	5.3
This work	2022	2.1-5.1	19x38.2x1.6	2.1~2.69

Chapter 6

Conclusion

The major objective of this project was to produce a set of specifications for the design of a microstrip patch antenna suitable for use with 5G networks. The impetus for this research was the fact that currently available antenna designs fall short of meeting all the requirements of 5G. This means that the antenna can't support all the features necessary for 5G. Specifically, they wanted to improve the antenna's bandwidth, return loss s1,1 parameter, and VSWR by tweaking the size of those parameters. Rogers RT-5880, with a height of Hs = 0.5mm, was utilized as the substrate of choice. Then, a 28GHz single-element antenna was built using those characteristics; it surpassed prior trials and satisfies 5G standards.

6.1 Achievements

In this study, we set out to identify the 5G requirements for the design of a microstrip patch antenna. The failure of currently available antennas to fully satisfy the requirements of 5G served as the impetus for this study. As a result, we endeavored to get superior results by altering the parameter dimensions in order to do this, a strategy that has been particularly fruitful with respect to the antenna's bandwidth parameter. Here, we utilized a Rogers RT-5880 substrate that had Hs = 0.5mm in height. Next, a 28 GHz single-element antenna was developed using those features; it achieved 5G compliance and outperformed the present work.

6.2 Limitations

The gain, directivity, and efficiency of the proposed antenna are all areas in which we are experiencing issues. The improvement of these qualities is necessary for the production of microstrip patch antennas that are suitable for use in 5G applications.

6.3 Future Work Field

Our gain, directivity, and efficiency were low when compared to prior studies, as was previously known from the preliminary findings and simulation discussion. Therefore, further effort may be made to enhance gain, directivity, and efficiency. To further assess the proposed and simulated antenna's performance, a physical prototype should be constructed and tested in the wild.

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