Addis Ababa University

Addis Ababa Institute of Technology (AAiT)

School of Electrical and Computer Engineering

Communication Engineering Graduate Program

Bandwidth Enhancement, Analysis, and Comparison of Microstrip Patch Antennas for Millimeter wave

by

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master's Science in Communication Engineering

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Declaration

I, declare that this thesis "Bandwidth Enhancement, Optimization, Analysis, And Comparison Of Microstrip Patch Antennas For 5G Mobile Communication" is my own work, that it has not been submitted before for any degree or assessment at any other university, and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

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Abstract

In the rapidly advancing landscape of wireless communication technology, there is a pressing need for antennas that are compact, lightweight, cost-effective, and have a low profile. Microstrip patch antennas have emerged as popular choices in numerous wireless communication applications due to their inherent benefits such as lightweight, compact size, affordability, ease of fabrication, and high reliability. However, these antennas encounter challenges, notably in the form of narrow bandwidth and low gain.

Various design factors influence the radiation properties of microstrip antennas, encompassing feeding techniques, substrate materials, patch configuration, and ground structures. This thesis is devoted to addressing the limitations of narrow bandwidth and low gain in microstrip patch antennas, specifically tailored for 5G mobile communication.

In this study, we enhanced a microstrip patch antenna's design to boost performance for 5G applications. By carefully adjusting its dimensions, the antenna achieved a bandwidth of 7.64% (2140 MHz), a return loss of -39.388 dB, and a VSWR of 1.021. These results show that our method significantly enhances the antenna's performance compared to previous designs, making it more effective for 5G communication.

Keywords

Microstrip patch antennas, 5G (fifth generation), Bandwidth, Parasitic Patch, and Gain.

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Abbreviations

3D	**T**hree-**D**imensional
3GPP	**T**hird **G**eneration **P**artnership **P**roject
4G	**F**ourth **G**eneration
5G	**F**ifth **G**eneration
AAiT	**A**ddis **A**baba **I**nstitute of **T**echnology
BW	**B**andwidth
CST	**C**omputer **S**imulation **T**echnology
dB	**D**ecibel
FDTD	**F**inite-**D**ifference **T**ime **D**omain
GHz	**G**igahertz
IEEE	**I**nstitute of **E**lectrical and **E**lectronics **E**ngineers
IoT	**I**nternet **O**f **T**hings
IP	**I**nternet-**P**rotocol
LOS	**L**ine **O**f **S**ight
LTE	**L**ong **T**erm **E**volution
MHz	**M**ega**H**ertz
MIMO	**M**ultiple-**I**nput **M**ultiple-**O**utput
mm-Wave	**M**illimeter-**W**ave
MSPA	**M**icrostrip **P**atch **A**ntenna
QOS	**Q**uality **O**f **S**ervice
RF	**R**adio **F**requency
SNR	**S**ignal-to-**N**oise **R**atio
VSWR	**V**oltage **S**tanding **W**ave **R**atio

Chapter 1

Introduction

1.1 Background

1.1.1 Antenna

Since antennas are used for both sending and receiving signals, they are extremely important components of communication systems. When an antenna receives a given signal, the radiation it emits is dispersed throughout space in a precise manner. It can be said that antennas are the backbone and nearly everything in wireless communication, without which the world could not have reached this time of innovation [1]. The growing demand for higher data rates, low latency, and better quality of service of mobile communications have led to a large number of inventions and technological advancements in past decades which is the prime goals of the upcoming 5th generation (5G) mobile networks [2]. Although the eternal antenna theory won't change, the impending 5G will update outdated norms and bring new and unexpected antenna innovations to the market. The underlying exploration on the empowering innovations for the upcoming 5G is progressively proposing the utilization of the millimeter-wave (mm-Wave) spectrum. The mmWave is a suitable candidate for 5G with its high frequency range from 30 to 300 GHz. Accordingly, the use of mm-wave, spectrum will require various designs of antennas in 5G communication systems. 5G will increase desired features like dependability, capacity, coverage, and throughput [2]. Tight antenna arrays with short distances between antenna elements are necessary to achieve 5G performance.

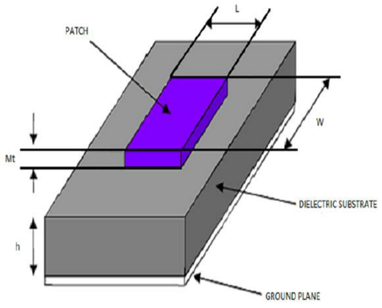


FIGURE 1.1: Microstrip Patch Antenna Structure
[5]

1.1.2 Microstrip Patch Antenna

A thin metallic patch placed over a ground plane is all that makes up a microstrip patch antenna. These antennas are lightweight, compact, and efficient, and they are commonly used at microwave frequencies for low-power applications. Rectangular and circular patches are the simplest and most common types of patches available. However, because microstrip antennas have a limited bandwidth by design, enhancement is usually required for practical applications. Thorough research into next-generation wireless (5G) technology may be a strong sign of an impending revolution in the industry to meet the rapidly growing demand and desires for high-speed communication as well as Internet of Things (IoT), wireless, and 5G based applications [3]. Recent telecommunications advancements have led to a massive improvement in communication methods, moving from rotary telephones that use an exchange to transfer the call from one destination to another by electronically switching the lines in between them to the most recent smartphones that do not require long cables to eliminate the communication gap. Researchers can investigate and hone fresh study ideas about the event thanks to the third-generation partnership project (3GPP), which suggests suitable improvements in wireless and 5G technology criteria. Smart phones will continue to use wireless and 5G technology, and a variety of IoT devices will be supported to carry out different tasks in a variety of life services, including smart cities, smart buildings, smart communication, and many more. These tasks may require a 5G antenna with low latency, high bandwidth and gain, low path loss, and a stable radiation diagram. Consequently, the author suggested several types of 5G antenna designs together with their features and traits.[4] Whether it is the era of radio waves or the era of the internet protocol (IP) suite, technology has advanced significantly over time, and with each advancement, some new features have been associated with changes. For example, in 4G technology, voice over IP is also possible, indicating that the internet can support communication as well. Another paper proposes a good bandwidth starting from 3.1 GHz to 4.2 GHz Slotted Planar Microstrip Patch Antenna, used in the first trials and introduction of 5G services, reciting the planning, simulation, execution, capacity, and experimental results[3]. 4G technology will save a substantial amount of time even though it offers a fast speed and streamlines the entire procedure. As 5G technology advances globally, the majority of industrialized countries are benefiting from it. The basic method of boosting the bandwidth and gain of the previously described antenna is to alter the substrate's basic characteristics and material height. It can be accomplished, nevertheless, by employing different optimization strategies, the same antenna design considerations, such as altering the ground plane or changing the radiation patterns, and minor changes in characteristic impedance. [6] Numerous academics have put forth various methods to increase the microstrip antenna's (MPA) gain and bandwidth, although it can be challenging to do so at the same time. Using circular microstrip patch antennas, the suggested construction incorporates certain innovative strategies that enhance performance overall, reduce return loss, and increase bandwidth. An apparatus made to emit or receive electromagnetic energy is called an antenna. Although electromagnetic waves are essentially emitted by everything, antennas are made to function well at particular frequencies and bandwidths [7].

1.1.3 Fifth Generation (5G)

The Fifth Generation, commonly known as 5G, had begun in late 2010. Among the many advantages of 5G technology are increased connectivity and coverage. The primary aim of 5G is the worldwide wireless World Wide Web. Customers may expect incredibly fast internet and multimedia experiences thanks to 5G's improved technologies. Advanced LTE networks are the source of supercharged 5G networks. 5G technology uses an unlicensed channel and millimeter waves to send data more quickly. [8]

1.1.4 5G's fundamental features

- It firmly supports the Wireless World Wide Web, or WWWW.
- It has both a high speed and a high capacity.

- At a rate of Gbps, it can broadcast massive volumes of data.
- offers newspapers, high definition TV show viewing, and excellent multimedia services.
- Compared to the previous generation, it sends data more rapidly.
- Features include voice, streaming video, interactive multimedia, rapid calling, clear audio and video, and a huge phone memory.
- It expanded the range of available multimedia services.
- Inexpensive per bit.
- It consumes more battery power.
- Implementing it is difficult.
- It requires the usage of sophisticated gear.[9]

1.2 Statement of the problem

The progression of wireless communication systems demands antenna solutions with low profiles that can exhibit exceptional performance across a broad frequency spectrum. In this context, Microstrip Patch Antennas (MSPA) stand out as a preferred choice for wireless devices, offering advantages such as low manufacturing costs, lightweight construction, a minimal footprint, and an inconspicuous configuration compared to bulkier antenna types. Despite being marketed as a flexible and affordable solution, MSPA's low gain and limited bandwidth make it less appropriate for 5G communication needs. The MSPA is straightforward and multifunctional, exhibiting adaptability in terms of polarisation, resonant frequency, pattern, and input impedance, despite these drawbacks. This makes patch antennas suitable for attachment to various platforms, including aircraft, spacecraft, rockets, satellites, cars, and even portable devices like cell phones. Recognizing the potential significance of Microstrip Patch Antennas in 5G applications, efforts are being made to overcome their limitations, particularly in addressing the narrow bandwidth and low gain issues, to harness their benefits in the context of evolving communication technologies.

1.3 Objectives Of The Research

1.3.1 General Objective

The general objective of this thesis is to design an enhanced rectangular microstrip patch antenna with substrate FR-4 at the operating frequency of 28GHz compatible for 5G mobile communication.

1.3.2 Specific Objectives

This thesis specifically aims to achieve the following specific goals:

- A single microstrip patch antenna was constructed and modeled to increase the bandwidth for 5G applications.
- designing the optimal antenna with increased bandwidth and gain for 5G applications by utilising a flawed ground structure.
- Using various dimensions, including insertion gap, patch width, patch length, etc., to design antennas for 5G applications.
- Compare the performance of the proposed method against other state-of-the-art demodulation schemes.
- Lastly, decide on the best antenna.
- to create and model a microstrip patch antenna with improved antenna characteristics, especially bandwidth, for 5G applications.
- to improve microstrip patch antenna performance.
- Comparing current 28 GHz microstrip patch antennas

1.4 Methodology

To achieve the aforementioned objectives the following methods will be used:

- Literature review: includes reading books, journals, and related work and other relevant about microstrip patch antenna, different types of substrates to be used, fifth generation (5G), and how to improve wireless communication.

- Data collection and analysis: System Modelling and Implementation: Determine microstrip patch antenna parameters, select patch width, patch length set substrate height , etc...

- Simulation and interpretation of the result: simulate the different types of antennas to find the different parameters like gain, directivity, VSWR, return loss and efficiency using software at 28 GHz frequency From the simulated results compare the approximated values of gain, directivity and efficiency provided by the different types of printed antenna arrays.

- Documentation: finally we will prepare the documentation from the above procedure and It will be held currently performance evaluation metrics. these techniques are briefly reviewed and discussed. It is observes survey that there is a particular relationship among gain, bandwidth and size of the microstrip antenna. It is recognized that if there is enhancement in one property are best suited to the fifth generation of mobile communications.

1.5 Literature Review

Numerous research papers and articles have developed into the performance analysis of various antennas, focusing on specific characteristics such as total scan pattern, gain, directivity, coverage efficiency, and return loss or VSWR individually. The following, among other things, are once again examined to align the current study with the issue at hand.
In [10] Using well-known HFSS software, an MPA antenna with an operating frequency of 47 MHz was built. The authors get to the conclusion that the bandwidth and other parameters can be enhanced by adding more slots to the ground plane. As 3G and 4G wireless networks compete for capacity, it is evident that a number of design flaws were brought into the market. The simultaneous connection of mobile stations to different networks is a basic feature of 4G networks. We must expand the network's bandwidth in order for it to correctly load the network's features, making this feasible. This paper's authors developed a number of different techniques for dividing up bandwidth among several servers.

in this study[11] proposes a 3x3 array antenna with a rectangular patch that operates at a 13 GHz operating frequency using HFSS. The report claims that the patch's VSWR, gain, and return loss were all enhanced by the addition of slots. Another technique for expanding bandwidth was put out in [12], where a multilayer patch was employed in the basic patch antenna and slots were added to the ground plane. This method has led to a 25 % increase in bandwidth.

Microstrip patch antennas are named after the outline of the radiating patch. Radiating patches can be rectangular, rectangular, circular, elliptical, triangular, circular ring, and ring eld. The design and analysis of microstrip patch antennas in square, rectangular, and circular shapes is straightforward. Because of these characteristics, they are more popular [13]. Since circular microstrip patch antennas only need to monitor one degree of freedom (radius), as opposed to two (length and breadth) as required by rectangular microstrip patch antennas, they are easier to utilise than rectangular ones. The most popular MPAs are rectangular and circular ones because they offer feedline tractability, circular/linear polarisation, numerous frequency operations, and flexible array construction. The antenna must be stimulated by feeding. Existing research employs a variety of feeding techniques, including coaxial probes, microstrip lines, aperture coupling, and proximity coupling [4]. in[14] Microstrip Patch Antennas (MPAs) are widely used in the field of communication due to their small size, lightweight, and ease of fabrication. Despite their advantages, one of the main challenges of MPAs is their narrow bandwidth and low gain, which limit their application in advanced communication systems such as 5G networks. Researchers have explored various methods to overcome these challenges. One promising approach is the development of a circular microstrip patch antenna (CMPA) with an innovative design to enhance performance metrics. A study proposed the use of a CMPA with a circular slot etched into the patch to achieve wideband operation. Using high-performance dielectric substrates like Rogers 5880, which has a thickness of 1.5 mm and a dielectric constant of 2.2, the antenna was constructed. Using the High-Frequency Structural Simulation (HFSS) tool, which is based on the Finite Element Method (FEM), the design and simulation process was completed. The proposed CMPA operates at an optimized frequency of 5.8 GHz, making it suitable for Wi-Fi communication and 5G networks. By introducing the circular patch design, the antenna achieves a bandwidth enhancement and a significant gain improvement, reaching 7.876 dB. This gain enhancement demonstrates that the proposed design successfully addresses the limitations of traditional MPAs, offering improved overall performance for next-generation communication systems.

the findings highlight that the use of advanced substrate materials and innovative design methodologies can significantly improve the performance of MPAs. By showcasing their potential for incorporation into 5G and other high-speed networks, the research advances the development of high-gain, wideband antennas for contemporary communication applications [14].

This thesis proposal intends to establish clear algorithms for Microstrip Patch Antennas. In other words, it aims to develop precise methodologies or procedures that govern the design, analysis, optimization, or operation of these antennas. These algorithms could cover aspects such as antenna design parameters, feeding techniques, material selection, impedance matching strategies, radiation pattern shaping, and performance evaluation metrics.

By defining these algorithms, the thesis seeks to contribute to the body of knowledge in antenna engineering by providing structured guidelines for designing and deploying Microstrip Patch Antennas, particularly within the evolving landscape of 5G communication networks.

1.6 Motivation

Almost all of our devices rely on the 5G wireless communication technology, which has become an essential part of our everyday existence. 5G has become a revolutionary force, in contrast to the constraints of 4G systems, which are marked by slow speeds, erratic connections, and insufficient streaming capabilities. As the need for mobile data continues to rise, 5G is becoming the go-to option due to its potential to provide stable, fast data transfer, more bandwidth, and significantly lower transmission latency than 4G.

The widespread adoption of 5G networks is not confined to personal use but extends to various industries, catering to diverse needs in wireless devices. In this context, the utilization of microstrip patch antennas proves to be particularly advantageous for 5G applications. These antennas offer enhanced features such as higher bandwidth, increased efficiency, low power consumption, and elevated gain. The significance of high gain is especially pronounced in antenna technology, ensuring optimal energy utilization and bolstering the overall performance of 5G systems.

1.7 Scope of the research

The critical theme of this thesis proposal is "Quality of Service Enhancement of 5G Communication Antenna Microstrip Patch Network." This study aims to explore the world of microstrip patch antennas and present a thorough analysis of their features and functionality. By using software simulations, the project aims to investigate different substrate materials, patch kinds, and operating frequencies and determine how these affect the quality of service provided by the antenna. The study will make use of sophisticated software simulations to examine how the microstrip patch antenna behaves in various configurations. This involves changing operation frequencies, patch kinds, and a methodical analysis of various substrate materials. The outcomes of these simulations will be meticulously analyzed to glean insights into the antenna parameters crucial for optimizing performance in the context of 5G mobile communication. Through this research, the aim is to contribute valuable knowledge and practical findings that can guide the enhancement of microstrip patch antennas, ensuring they meet the stringent requirements of 5G communication networks. The results derived from the software simulations will serve as a foundation for informed decision-making in the design and optimization of microstrip patch antennas for superior Quality of Service in the dynamic landscape of 5G mobile communication.

1.8 Contributions of the Research

This thesis enhances the understanding of microstrip patch antennas for 5G communication by introducing new ideas and design principles that could guide future research. The findings aim to improve antenna designs, which will contribute to better bandwidth in 5G networks. This research will assist network engineers and telecommunications professionals in making more informed decisions for efficient 5G communication. Ultimately, the thesis seeks to bridge theory and practice, advancing microstrip patch antenna technology to enhance bandwidth in 5G networks.

1.9 Research Layout

Chapter 1: Introduction This chapter provides an introduction to the thesis, outlining the problem statement, objectives, methodology, and motivation of Microstrip Patch Antennas in 5G mobile communication applications.

Chapter 2: Literature Reviews In this chapter, a comprehensive review of the paper and an overview of some of

the recent advances of research in the area of Microstrip Patch Antennas in 5G applications.

Chapter 3: Analysis, design, implement, and analyze microstrip patch antennas for the optimization of Quality of Service in 5G communication.

Chapter 4: Results and Discussion This chapter presents and compares simulation results obtained from the simulation results in CST software and Matlab.

Chapter 5: Conclusion and Future Work The final chapter serves as a conclusion to the thesis, summarizing key findings and presenting suggestions for future research and development in the field of microstrip patch antenna For 5G Mobile communication.

Chapter 2

Antenna parameters

2.1 Antenna Parameters

During the design and measurement phases, antenna characteristics are crucial in defining the performance features of antennas. This section provides a thorough review of the behavior of the antenna by elucidating a number of important features. S-parameters, input impedance, return loss, gain, efficiency, radiation pattern, directivity, bandwidth, and other crucial elements are all being considered. Each of these characteristics adds considerably to the knowledge and optimization of antenna performance in various communication contexts. The following elucidations explore the nuances of these properties, providing insight into their functions and consequences within the field of antenna engineering.

2.1.1 Radiation Pattern

An antenna's relative power of a radiated field in various directions is used to express the radiation pattern. The spatial distribution of a quantity that describes the electromagnetic field produced by an antenna is how it is defined. The radiation pattern refers to the spatial distribution of radiation intensity, field strength, directivity, phase, polarization, power flux density, or radiation intensity in two or three dimensions. The pattern of radiation varies with the observer's position along a path or surface with a fixed radius, passing through the direction where the most radiation occurs. To visualize the radiation pattern, the spherical coordinate system is typically used. A two-dimensional pattern can be a function of the elevation angle, θ, at constant azimuth angle,Φ, or a function of Φ at constant

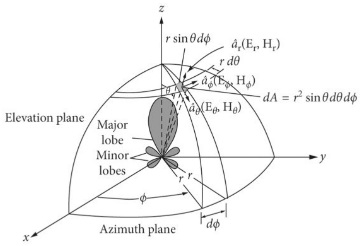


FIGURE 2.1: spherical coordinate systems for antenna [16]

θ value The spherical coordinate system is shown in 2.2. The three sections of an antenna's radiation fields are farfield, radiating near-field, and reacting near-field. The radiation pattern is not the same at great distances as it is in the vicinity of the antenna. An antenna element is surrounded by a reactive near-field, a field pattern where it is extremely difficult to forecast the electric and magnetic fields. The radiating near-field takes over a short distance from the reactive near-field, and this is the area where an antenna's radiation field is forming. The term "far field" refers to the field pattern at great distances. What is most frequently of interest is the far field, which is the radiated power, also known as the radiation field. Since it makes computations easier, measurements and beam patterns are typically seen in the far-field region. [15]

2.1.2 Directivity

Because antennas will be compared using this figure of merit, one of the most crucial aspects in this work is an antenna's directivity. [17] defined an antenna's directivity as "the ratio of the radiation intensity in the guidance provided by the average radiation intensity across all directions from the antenna." The average radiation intensity, U0, is calculated by dividing the total power emitted by the antenna by 4π, which is the radiation intensity of an isotropic source. This can be expressed as:

$$D(\theta, \phi) = \frac{U(\theta, \phi)}{U_0} = 4\pi \frac{U(\theta, \phi)}{P_{rad}} \tag{2.1}$$

Where D is the directivity of the antenna U is the radiation intensity of the antenna U0 is the radiation intensity of an isotropic source Prad is the total power radiated Since directivity is the ratio of two radiation intensities it is a dimensionless quantity. Hence, it is generally expressed in dB. The directivity of an antenna permits to determine in which directions the antenna radiates with

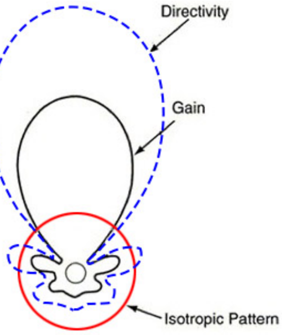


FIGURE 2.2: Diagram of Directivity and Gain
[16]

more or less intensity compared with an isotropic source. An antenna with a thin main lobe is more directional because it has better directivity than one with a wide main lobe.

2.1.3 Gain

The definition of gain in a particular direction is "the ratio of the intensity to the radiation intensity that would be obtained if the power accepted by the antenna were transmitted isotropically." Given that the gain takes into consideration both conduction and dielectric efficiency, it is evident that directivity and definition are strongly related. The relationship between the antenna gain and directivity can be expressed by equation 2.2:

$$G(\theta,\phi) = 4\pi\frac{U(\theta,\phi)}{P_{in}} = 4\pi\eta\frac{U(\theta,\phi)}{P_{rad}} = \eta D(\theta,\phi) \tag{2.2}$$

Where G is the gain of the antenna, D is the directivity of the antenna.

P_{in} = total input power [W]
η= antenna efficiency $(0 < \eta < 1)$

2.1.4 Antenna Efficiency

During the design and measurement phases, antenna characteristics are crucial in defining the performance features of antennas. This section provides a thorough review of the behavior of the antenna by elucidating a number of important features.Among the crucial elements being considered are directivity, bandwidth, radiation pattern, gain, efficiency, input impedance, return loss, and S-parameters. Understanding and improving antenna performance in a variety of communication scenarios depends heavily on each of these factors. The intricacies of these characteristics are examined in the following explanations, which also shed light on their applications and implications in the field of antenna engineering. Then, the total efficiency of an antenna is defined as follows,

$$e_0 = e_r e_c e_d \tag{2.3}$$

Where, e0 is the total efficiency. er = mismatch reflectioneffectiveness Conduction efficiency, or ec Dielectric efficiency, or ed

Where, e0 is the total efficiency.
er = mismatch reflection efficiency
Conduction efficiency, or ec
Dielectric efficiency, or ed
The antenna's radiation efficiency is a multiplication of the conduction efficiency and the dielectric efficiency. The loss is due to: conduction and dielectric, this is called the I^2R losses.

2.1.5 Input Impedance

An antenna's input impedance can be defined as "the impedance presented by an antenna at its terminals or the proportion of the voltage to the current at both terminals or the proportion of the proper components of the electric to magnetic fields at a point" [5]. The matching of an antenna is greatly influenced by it, hence it must always be considered while designing one. A port and an antenna can minimize unwanted reflections by matching their impedances appropriately. Because these two impedances perceive one another as comparable, the reflection is reduced. In terms of numbers, input impedance is the sum of the reactances and resistances at the antenna's terminals. The antenna's impedance can therefore be expressed using equation 2.4.

$$Z_{in} = R_{in} + X_{in} \tag{2.4}$$

Where, Z_{in} is the antenna impedance
R_{in} is the antenna resistance
X_{in} is the antenna reactance
The input impedance's imaginary component, Xin, stands for the power that is stored in the antenna's near field. Radiation resistance (Rr) and loss resistance (RL) make up the input impedance's resistive portion, Rin. The power dissipated in the loss resistance is lost as heat in the antenna itself as a result of conducting or dielectric losses, whereas the power associated with the radiation resistance is the power that the antenna actually radiates. The excitation technique, the geometry of conducting items, their conductivity properties, and the properties of nearby objects all affect the input impedance. Certain antennas rely on dielectric materials or slots in a plane, for instance, to reverberate, and they are not reliant on conducting metals. Other properties, including the dielectric's permittivity, affect their input impedance [5]. Impedance matching to minimize reflections is achieved by making the input impedance equal to the source impedance as given in equation 2.7.

$$Z_{in} = Z_s^* \tag{2.5}$$

Where
$Z_{in} = R_{in} + jX_{in}$
$Z_s = R_s + jX_s$ Zs is the source impedance
Rs is the source resistance
Xs is the source reactance
Maximum power transfer occurs when Zin is the complex conjugate of Zs. In other words, $R_{in} = R_s and X_{in} = -X_s$. This is sometimes referred to as complex conjugate matching. A metric known as the Voltage Standing Wave Ratio (VSWR) can be used to characterise the generation of standing waves, which occur when the matching condition is not met because some of the power may be reflected back, preventing all of the power from reaching the target location. The "function of reflection coefficient," or VSWR, is a measurement of the antenna's reflected power. Using equation 2.7, the value of VSWR is determined when the coefficient of reflection is Γ.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2.6}$$

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_{in} - Z_s}{Z_{in} + Z_s} \tag{2.7}$$

Where, $\Gamma$is called the reflection coefficient
V_r is the amplitude of the reflected wave
$V_i$is the amplitude of the incident wave
The impedance mismatch between the transmitter and the antenna is essentially measured by the VSWR. The more the mismatch, the higher the VSWR, which shouldn't be bigger than 3. When the VSWR is at least one, a perfect match is achieved. It is ideal in that case because the antenna does not reflect the power. Equation 2.9 demonstrates that the antenna with a lower VSWR has a better return loss than the other antenna with a higher VSWR. Given that the majority of radio equipment is designed for this impedance, a reasonable antenna design should have an input impedance of $50W$ or $75W$.

2.1.6 Return Loss

This metric is used to quantify the power that the antenna reflects as a result of the transmission line and antenna not matching. Thus, the return loss is a parameter like the VSWR to demonstrate how well the matching between the transmitter and receiver has occurred. Its measurement describes the ratio of the reflected power in the reflected wave to the power in the incident wave in units of decibels [12].
The Return Loss is given by:

$$ReturnLoss = -20 \log |\Gamma| (dB) \tag{2.8}$$

where the reflection coefficient's magnitude is always represented by the symbol$|\Gamma|$. For ideal matching between the transmitter and the receiver, $\Gamma = 0$ and $R_L = 1$ which implies no power would be reflected back, whereas a $\Gamma = 1$ has a RL = 0dB, which implies that there is nothing to radiate by the antenna because the power provided to the antenna is completely reflected. The Return Loss can also be calculated from the VSWR using equation 2.11. Keep in mind that the return loss is stated as a decibel ratio.

$$ReturnLoss = -20 \log \frac{VSWR - 1}{VSWR + 1} dB \tag{2.9}$$

A negative number is used to represent the return loss. Since the returning power must be less than the forward power in order to be considered a loss, it has a negative sign, therefore, a loss is represented by negative decibels.

2.1.7 S-parameters

In microwave design, the S-parameters are crucial for characterising how electrical devices behave. The majority of electrical characteristics, including as gain, return loss, and VSWR, are related to the S parameters. The input-output relationship between ports in an electrical system is described by S-parameters. While S21 is the forward transmission coefficient (gain) and S12 is the reverse transmission coefficient (isolation), which gauges the power transferred from port 1 to port 2, S11 and S22 are the S-parameters for input and output reflection [18]. S11, also referred to as return loss, is the reflection coefficient since it shows the amount of power reflected from the antenna. If S11 = 0 dB, no power is released and all of it is reflected from the antenna.

2.1.8 Bandwidth

An antenna's bandwidth is the range of frequencies over which it may function properly in terms of particular features. The features that are often stated include the VSWR, gain, and radiation pattern. The VSWR is typically selected as the bandwidth consideration parameter; this bandwidth is referred to as the impedance bandwidth. For a given band, bandwidth is the difference between the higher frequency (F_H) and lower frequency (F_L), as equation 2.10 illustrates.

$$BW = F_H - F_L \tag{2.10}$$

Another way to express the bandwidth is as a percentage of the band's centre frequency, which is as follows:

$$BW = 100 \times \frac{F_H - F_L}{F_c} \tag{2.11}$$

where, FC is the band's centre frequency,
FH is its highest frequency, and
FL is its lowest frequency.

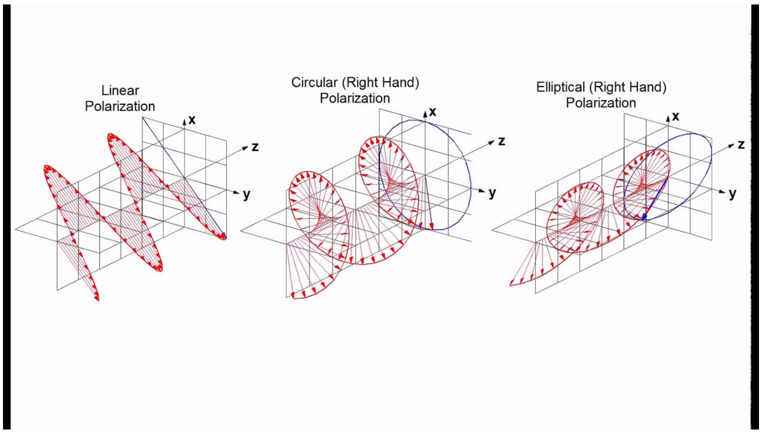


Figure 2.3: Polarization Linear, Circular, Elliptical.
[19]

2.2 Polarization

When the antenna generates a wave, its electric field determines its polarization. The antenna is polarised according to the electric field's phase and amplitude. All of the elements of the electric field are equal at the antenna if the phases and magnitudes are linearly polarised. A circularly polarised antenna is one in which the phases are 90 degrees apart but the magnitudes are equal. In order for two linearly polarised antennas to communicate, their projected electric fields must coincide. A circularly polarised antenna, on the other hand, may communicate with any linear antenna, independent of orientation. Because the radiation from a linear antenna is concentrated in one direction rather than being split between the two components, it emits more power than a circular antenna. In order to be readable from any angle, the tag antenna should preferably be circularly polarised. Depending on the application, a reader antenna can be either linear or circular.[20]. In Figure 2.3, three types of polarization are shown.

Chapter 3

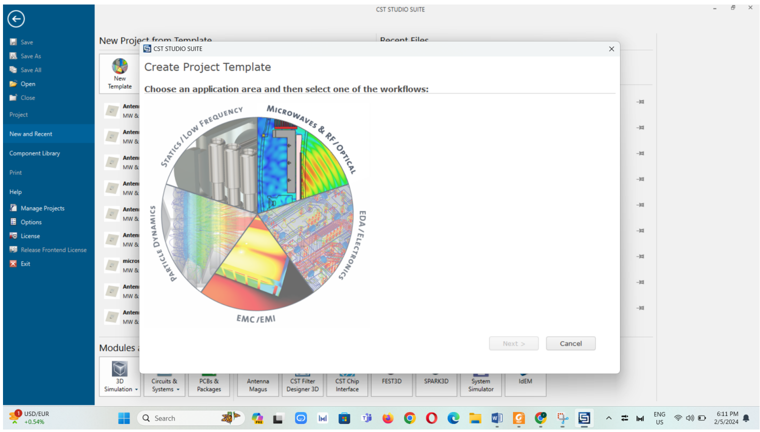
Antenna Design

3.1 Designing procedure

This study focuses on investigating the performance characteristics of antennas, with a specific emphasis on the rectangular patch shape due to its simplicity in design and analysis, as well as its inherent wide bandwidth in contrast to other forms. Figure 3.1 shows the physical configuration of the Microstrip Patch Antenna (MSPA) that is being studied. The FR-4 substrate material used to build the MSPA has the following characteristics: a 0.0025 loss tangent, a 4.3 relative permittivity (ϵ_r), and a radiating copper metal thickness of 0.035 mm. The intended frequency of operation for this design is 28 GHz. A number of important measures, such as bandwidth, directivity, gain, radiation efficiency, and return loss, are used to assess the MSPA's performance. Several methods, including quarter-wavelength impedance transformers, inset-feed impedance matching, and antenna size adjustment, are used to maximize these performance metrics.

3.1.1 Softwares

One example of computer simulation technology that is a very sophisticated tool for three-dimensional modeling of high-frequency components is CST Microwave Studio (CST MWS), as seen in figure 3.1. CST MWS specializes in the rapid and precise management of electromagnetic compatibility (EMC) and signal integrity (SI) issues, as well as the research of high-frequency (HF) devices, such as filters, couplers, antennas, single and multi-layer structures. Maxwell's integral equation,



Create Project Template

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

FIGURE 3.1: View of the CST studio suite application at launch

a fundamental idea in electromagnetic theory, is discretized in CST MWS, as described in the Computer Simulation Technology handbook. This discretization process allows for a detailed and accurate representation of the behavior of electromagnetic fields in complex structures. Additionally, CST Microwave Studio's computational engine uses central finite difference methods to calculate temporal derivatives. This choice of numerical methods reflects the commitment to accuracy and efficiency in the simulation of high-frequency phenomena. CST MWS is noted to leverage the Finite-Difference Time-Domain (FDTD) approach, a widely used numerical method in electromagnetics. This method is known for its versatility in handling complex geometries and transient phenomena. According to various guides, CST MWS's unparalleled performance establishes it as the preferred choice for technology-driven research and development (R andD) departments. Its ease of use ensures that it is a tool accessible to a broad range of users, providing rapid insights into the electromagnetic behavior of high-frequency designs. The combination of accuracy, versatility, and user-friendly features positions CST MWS as an indispensable resource for those engaged in advancing technology through research and development.[21]

3.1.2 Steps

Step 1: To increase bandwidth for 5G applications, design a microstrip patch antenna.
Step 2: Second, several dimensions are utilized to determine the optimum option based on 5G requirements.
Step 3: Now, depending on the 5G requirement, utilize a feeding approach to obtain a decent outcome.

Step 4: A feeding mechanism with different dimensions, a substrate height, and a substrate material are used to create an antenna for 5G applications.
Step 5: Run the antenna simulation after saving the project If it satisfies the requirements, proceed to save the outcome.
Step 6: Optimize the design if you're not happy with the result.
Step 7: Improve the performance of the microstrip patch antenna that was designed.
Step 8: Analyze our results against those of other antennas.

3.2 Antenna Design by Equation

Achieving particular performance qualities at a specified operating frequency is the main goal of antenna design. There are several crucial elements involved in starting the design process for a rectangular Microstrip Patch Antenna (MSPA). First, the substrate type, substrate thickness, and operation frequency are chosen. The next stage after this is to ascertain the antenna structure's dimensions, as shown in Figure 3.1. This includes ground plane dimensions as well as substrate height, breadth, and length of the patch. Several formulae specifically designed for the construction of rectangular MSPAs serve as a reference for the dimensioning of these characteristics. These formulas are essential for figuring out the ideal antenna dimensions needed to satisfy the required performance standards. Some of the fundamental equations governing the design process are outlined below.

3.2.1 Height of the Substrate

The free-space wavelength λ_0 is strongly related to the height of a microstrip antenna, which is commonly referred to as substrate thickness or substrate height (SH). The typical range for the substrate thickness is between $0.003\lambda_0$ and $0.05\lambda_0$, where λ_0 is the free-space wavelength.

More thorough formulas are used to determine the substrate height, taking into account variables like the effective dielectric constant, the intended operating frequency, and the substrate material's dielectric characteristics. Depending on the intricacy of the antenna design and the required degree of precision, these equations may contain mathematical formulations taken from electromagnetic field analysis or transmission line theory.

These calculations are crucial in determining the substrate height that ensures optimal performance and impedance matching for the microstrip antenna design. They play a significant role in achieving the desired antenna characteristics and performance at the specified operating frequency.[22]

$$SH = \frac{0.3c}{2\pi f_0 \sqrt{\epsilon r}} \tag{3.1}$$

3.2.2 Patch Width

The width of the patch (PW) has a lesser impact on the resonant frequency and radiation pattern of the antenna. However, it plays a significant role in determining the antenna's bandwidth and radiation efficiency. To calculate the patch width, a specific equation or methodology is typically employed, which may be referenced from literature or derived based on the specific design requirements and substrate properties. These calculations consider factors such as the desired bandwidth, substrate material properties, and antenna dimensions. It's essential to accurately determine the patch width as it directly influences the radiation efficiency and bandwidth performance of the antenna. Fine-tuning this parameter ensures that the antenna meets the desired specifications and achieves optimal performance characteristics.

$$PW = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{3.2}$$

3.2.3 Dielectric Constant

An important factor in influencing the electrical properties and functionality of a microstrip antenna is the dielectric constant, sometimes referred to as relative permittivity, of the substrate material. A number of factors, including the antenna's bandwidth, radiation pattern, and impedance matching, are impacted by the dielectric constant. A higher dielectric constant substrate in microstrip antennas usually results in a smaller antenna's physical size for a given operating frequency.

Typical dielectric constants (ϵ_r) for substrate materials used in microstrip antennas can vary widely, ranging from around 2 for air to 10 or more for certain types of ceramics or specialized dielectric materials. Popular substrate materials like FR4 have a dielectric constant of around 4.4, while materials like Rogers RT/-duroid 5880 have a dielectric constant of around 2.2. Choosing the right dielectric constant for the substrate involves a trade-off between various factors such as antenna size, bandwidth, and manufacturing cost, among others. It's usually a crucial design parameter in optimizing the performance of microstrip antennas. In that case, we are going to choose the operating frequency (fo) as 28 GHz and use FR4 as the substrate material, with a relative permittivity of the substrate.

3.2.4 Patch Length

The specific length of the patch is a crucial factor in patch antenna design. It regulates the resonant frequency due to the patch's intrinsically small bandwidth. There are occasions when the patch length is chosen between 0.333 λ_0 < PL < $0.5\lambda_0$. Therefore, a variety of equations or design techniques are used to determine the actual patch length (PL). The intended operating frequency, the characteristics of the substrate material, and the antenna size are all taken into consideration in these computations. The performance of the antenna can be maximized and the desired resonance frequency can be reached by designers by precisely calculating the patch length.

$$PL = PL_{eff} - 2\Delta PL \tag{3.3}$$

3.2.5 Length of the Inset

It is essential to match the patch to a 50Ω feeder line by using the inset length (Y_0). The impedance at the patch edge should ideally be high, usually around 300Ω. But when the inset point approaches the patch's center, the impedance rapidly drops. Equation 3.8 can be used to determine the inset length (Y_0), which is obtained to guarantee that the patch and the 50 Ω feeder line have matching impedances. The feed point can be precisely positioned using this formula to provide impedance matching and optimal performance for the microstrip patch antenna design. In order to accomplish the required impedance matching and guarantee effective power transfer between the antenna and the feeder line, the proper inset length (Y_0) must be determined using Equation 3.8.

$$Y_0 = \left(\frac{PL}{\pi}\right) \cos^{-1}\left(\sqrt{\frac{Z_0}{Z_L}}\right) \tag{3.4}$$

3.2.6 Feed Point Location

To calculate the feed point location (Xf, Yf) for the rectangular Microstrip Patch Antenna (MSPA) in X-Y coordinates, a specific formula is utilized. This formula enables the determination of the coordinates for optimal feeding of the antenna. While the exact formula may vary depending on the specific design considerations and methodology employed, it typically involves factors such as the inset length, patch dimensions, and desired impedance matching. The calculation of feed point locations is crucial for ensuring efficient power transfer between the antenna and the feeder line, as well as achieving desired impedance matching and radiation characteristics.

$$X_f = \frac{PL}{2\sqrt{\epsilon_{reff}}} \tag{3.5}$$

$$Y_f = \frac{PW}{2} \tag{3.6}$$

3.2.7 Ground Plane Dimension

The Microstrip Patch Antenna's (MSPA) rectangular length and breadth ground plane are usually intended to be greater than the patch's dimensions in order to guarantee that it completely encompasses the patch and the feed line. This guarantees that the antenna's radiation beams, which surpass the patch's actual size, are suitably confined within the ground plane. Frequently, particular formulas adapted to the antenna design specifications and intended performance attributes are used to determine the ground plane dimensions. Although the precise formula may change, it usually takes into account elements like impedance matching, efficiency, and the intended radiation pattern.

$$GL = PL + 6SH \tag{3.7}$$

$$GW = PW + 6SH \tag{3.8}$$

The table shows the design parameters of a microstrip patch antenna, comparing the initial calculated values with the optimized values used in the final design. Some parameters, like the width and length of the patch, feed line, and inset, are adjusted to improve the antenna's performance, such as achieving better bandwidth, return loss, and impedance matching. Other parameters, like the substrate and ground plane dimensions, remain the same in both the calculated and optimized designs. The optimizations help ensure the antenna meets the required performance for 5G applications.

Design parameter	Symbol	Calculated value
Width of patch	Aw	3.289
Length of patch	Al	1.747
Width of feed line	Tw	2
Length of inset	Il	0.4
Width of inset	Iw	0.4
Width of substrate	Subw	10
Length of substrate	Subw	10
Width of ground plane	Gw	10
Length of ground plane	Gl	10
Height of substrate	H	1.5
Thickness of ground plane	T	0.035

TABLE 3.1: Design parameters of the antenna structure

3.3 Techniques

3.3.1 Optimazation Techniques

In this thesis, different optimization techniques were used to improve how well the microstrip patch antenna performs. However, We employ the parametric sweep method in CST Studio. the parametric sweep technique was applied to adjust parameters like patch size, substrate thickness, and air gap, analyzing their effects on bandwidth, gain, and return loss. Additionally, genetic algorithms (GA) and particle swarm optimization (PSO) were used to automatically find the best parameter combinations for achieving the desired performance. These methods helped enhance the bandwidth and efficiency of the antenna while meeting the design requirements.

Design parameter	Symbol	Optimized value
Width of patch	Aw	8.15
Length of patch	Al	3.75
Width of feed line	Tw	2.94
Length of inset	Il	0.843
Width of inset	Iw	0.56
Width of substrate	Subw	10
Length of substrate	Subw	10
Width of ground plane	Gw	10
Length of ground plane	Gl	10
Height of substrate	H	1.5
Thickness of ground plane	T	0.035

TABLE 3.2: Optimized value of antenna parameter

3.3.2 Parasitic Patch Techniques

Parasitic patch techniques are used in antenna design to improve performance without requiring separate feeding for each element. In this method, parasitic elements are placed near the driven patch to shape the radiation pattern and achieve higher gain, directivity, or bandwidth. These techniques enhance antenna performance by optimizing the size, shape, and placement of the parasitic elements. This is especially useful for applications requiring high gain and directional radiation, such as long-distance communication or radar systems. [23].

These techniques also simplify antenna designs compared to complex phased arrays, reducing costs and making them ideal for compact, low-profile antennas. By adjusting the parasitic elements, the antenna's bandwidth can be broadened, improving impedance matching across a wider frequency range. Parasitic patch techniques are widely used in fields like telecommunications, satellite communication, radar, and 5G systems, where efficiency, compactness and high performance are crucial.[24].

3.3.2.1 Types of parasitic patch

Parasitic patches can be classified based on their position relative to the driven patch as follows:

- Co-Planar Parasitic Patch: In this configuration, the parasitic patch is placed on the same plane as the driven patch, typically on the same substrate.

This arrangement is commonly used for improving impedance matching, bandwidth, and gain while maintaining a compact antenna design.

- Stacked Parasitic Patch: Here, the parasitic patch is positioned above the driven patch with a vertical separation, often using a spacer or another substrate layer. This design is effective in achieving bandwidth enhancement and higher gain, as the stacked layers interact constructively with the electromagnetic field.
- Side-by-Side Parasitic Patch: In this setup, parasitic patches are placed adjacent to the driven patch on the same substrate. This arrangement is used to modify the radiation pattern and improve directivity.

Design parameter	Co-Planar Parasitic Patch	Stacked Parasitic Patch
Width of Parasitic	1.875	2.346
Length of Parasitic	0.46	1.875
gap between patch	0.5	0.7
Thickness of Parasitic	1.635	1.9

Table 3.3: Design parameter of parasitic patch

Chapter 4

Result and Discussion

This section explores how different antenna parameters affect the overall performance of the antenna system. It carefully examines each parameter, ensuring every detail is considered. These parameters form the foundation for designing the antenna, and analyzing the resulting performance helps make necessary improvements.

4.1 Simulation Results of Calculated Designed Antenna

As a result of the simulation, the designed microstrip patch antenna's S-parameter, shown in Figure 4.1, indicates that the return loss at the frequency center, 27.459 GHz, is -60. db. The antenna's operating frequency ranges from 26.722 GHz to 27.950 GHz, with corresponding to a bandwidth of 1.228 GHz (4.38%).

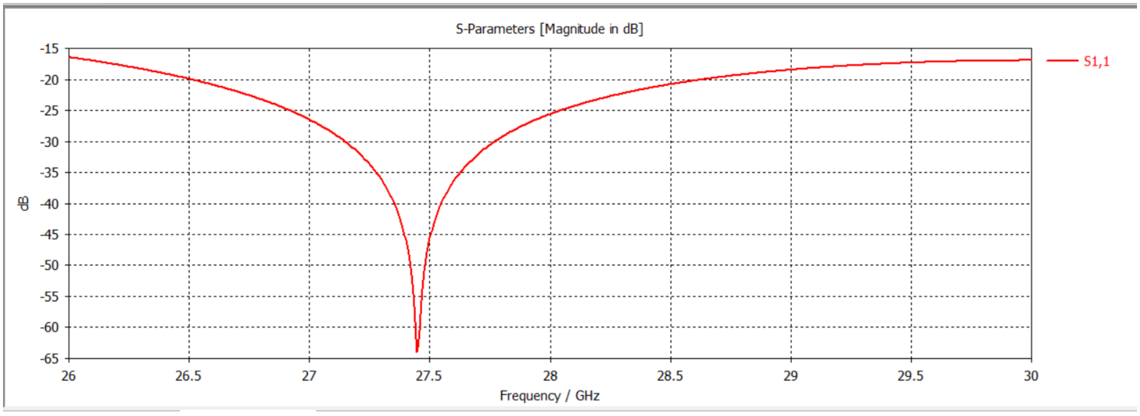
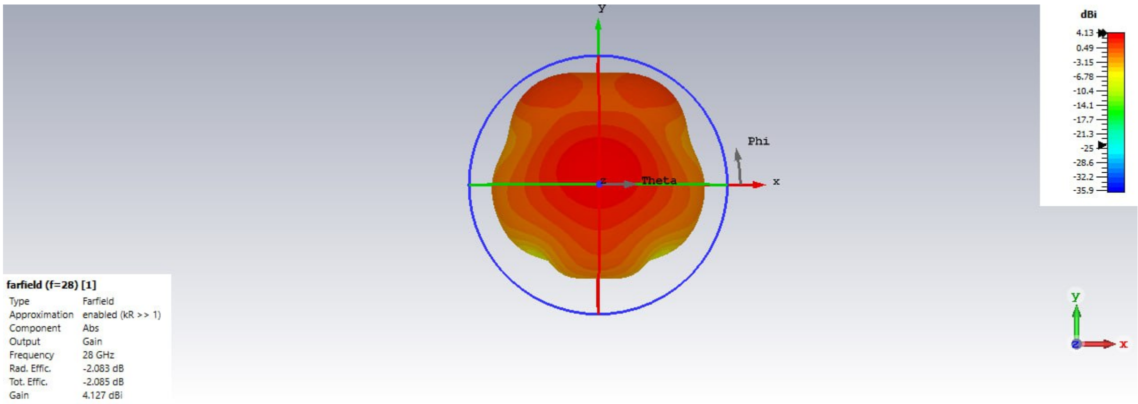


FIGURE 4.1: S-parameter Patch Antenna



farfield (f=28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	28 GHz
Rad. Effic.	-2.083 dB
Tot. Effic.	-2.085 dB
Gain	4.127 dBi

FIGURE 4.2: directivity of microstrip antenna

Despite the calculated values, the designed antenna fails to achieve the desired operating frequency of 28 GHz. To overcome this limitation and enhance performance, we employed an optimization technique through parameter sweeping.

4.1.1 Result for optimized design antenna

4.1.2 Microstrip Antenna performance with stacked parasitic patch

As a result of the simulation, the designed microstrip patch antenna's S-parameter, shown in Figures, indicates that the return loss at the frequency center, 28 GHz, is -45. db. The antenna's operating frequency ranges from 26.952 GHz to 29.074 GHz, with corresponding to a bandwidth of 2.122 GHz (7.58%). the radiation efficiency of microstrip antenna with the stacked parasitic patch is 71%.

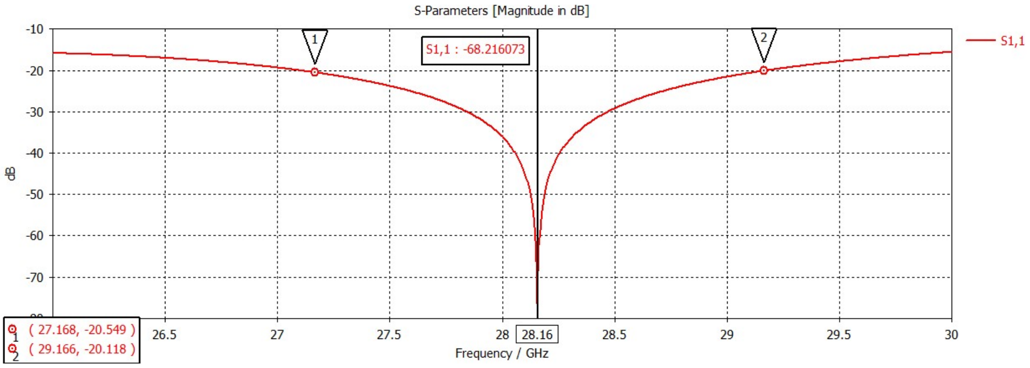
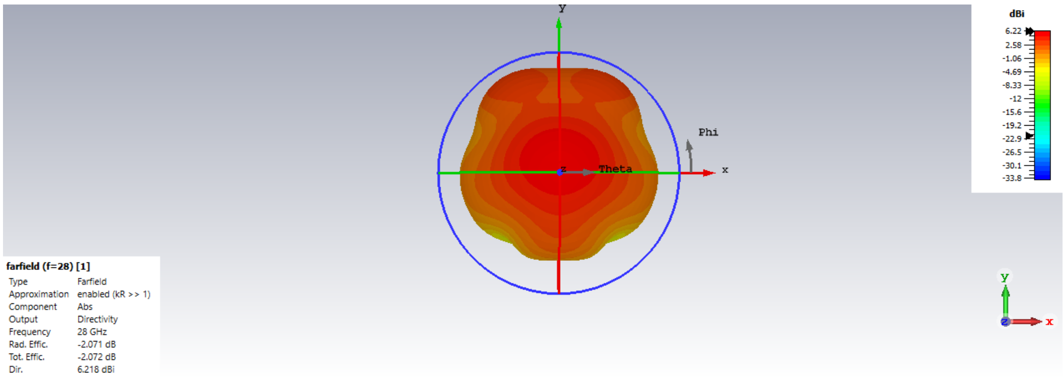


FIGURE 4.3: S parameter optimized patch antenna



farfield (f=28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	28 GHz
Rad. Effic.	-2.071 dB
Tot. Effic.	-2.072 dB
Dir.	6.218 dBi

FIGURE 4.4: directivity of optimized patch antenna

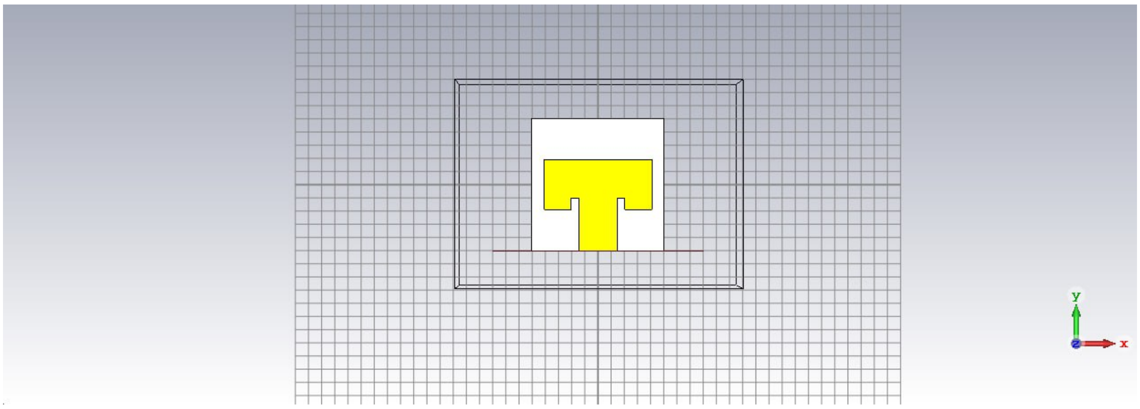


FIGURE 4.5: optimized patch antenna

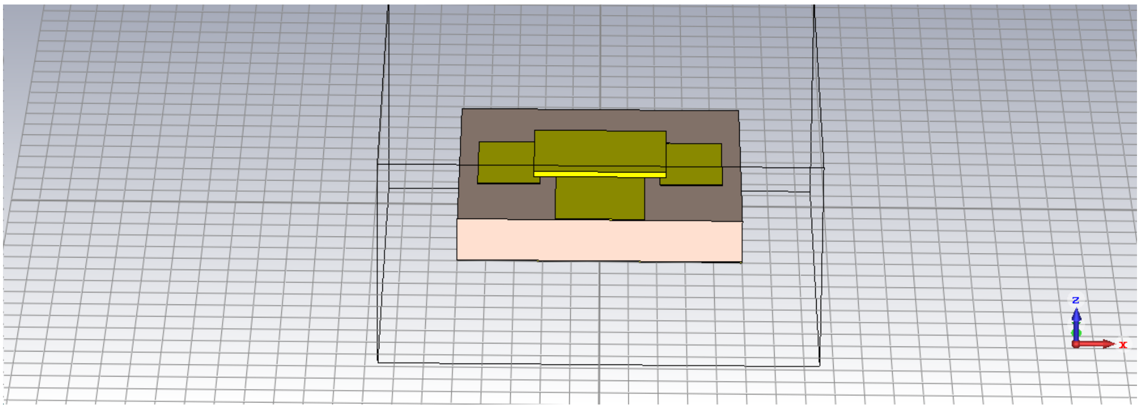


FIGURE 4.6: designed microstrip Patch Antenna with stacked parasitic patch

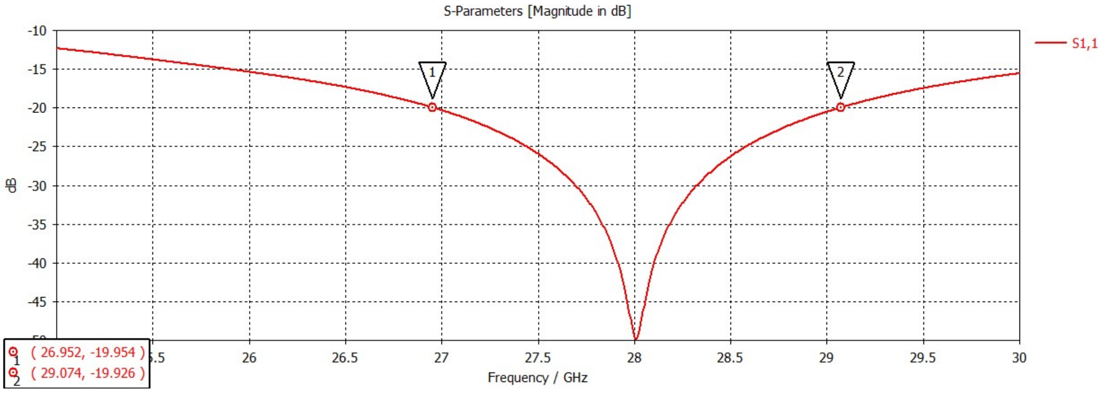
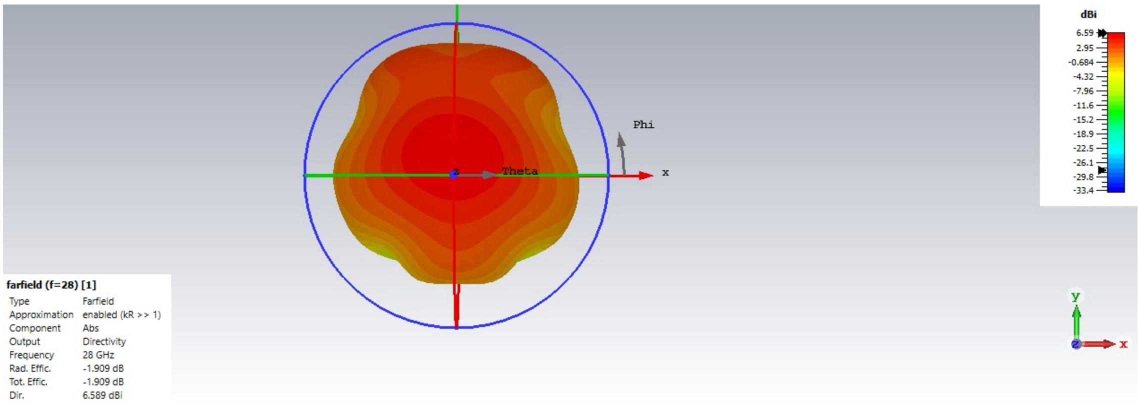


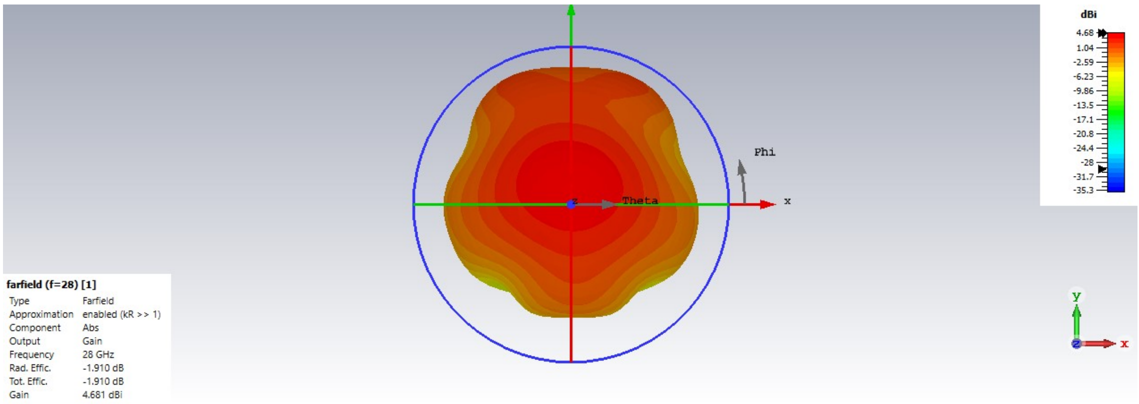
FIGURE 4.7: S-parameter microstrip Patch Antenna with stacked parasitic patch



farfield (f=28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	28 GHz
Rad. Effic.	-1.909 dB
Tot. Effic.	-1.909 dB
Dir.	6.589 dBi

FIGURE 4.8: directivity microstrip Patch Antenna with stacked parasitic patch



farfield (f=28) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 28 GHz
Rad. Effic. -1.910 dB
Tot. Effic. -1.910 dB
Gain 4.681 dBi

FIGURE 4.9: gain microstrip Patch Antenna with stacked parasitic patch

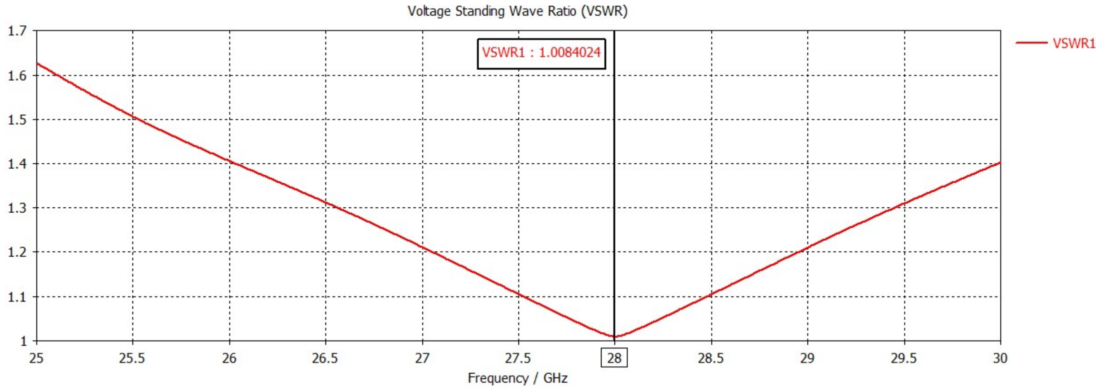


FIGURE 4.10: VSWR of microstrip antenna with stacked parasitic patch

Antenna Parameters	Result/ Output
Return loss(S1,1)	-45
Bandwidth	7.58%
Gain	4.68dBi
Directivity	6.589dBi
VSWR	1.008
Efficiency	71%
Power Simulated	100%

TABLE 4.1: Simulated results of antenna parameters for 28 GHz operating frequency using stacked patch

4.1.3 Microstrip Antenna performance with Co-Planar Parasitic Patch

At an operating frequency of 28 GHz, the Co-Planar Parasitic Patch antenna-based microstrip patch antenna has a 2.14 GHz (7.64%) bandwidth, a variety of frequencies from 26.915 GHz to 29.055 GHz, and a return loss of -39.39 dB.64% radiation efficiency.

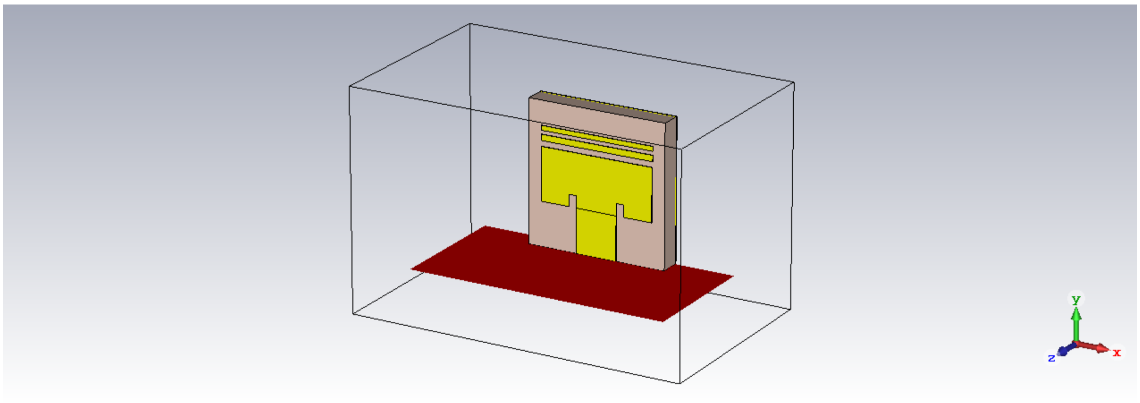


Figure 4.11: Designed Antenna

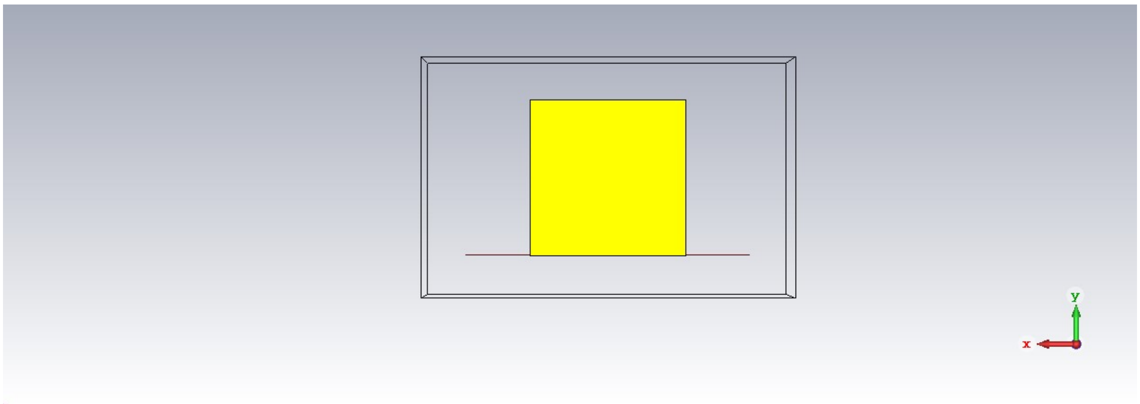


Figure 4.12: back 2D

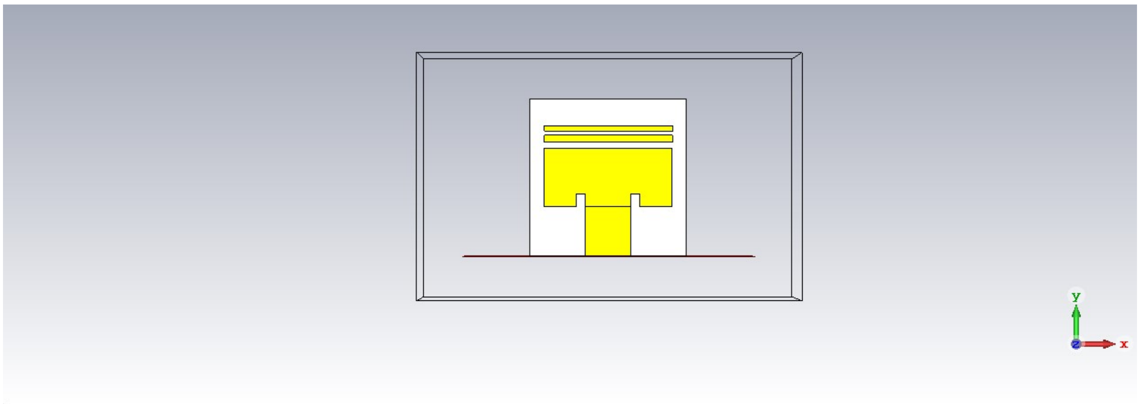


FIGURE 4.13: front 2D

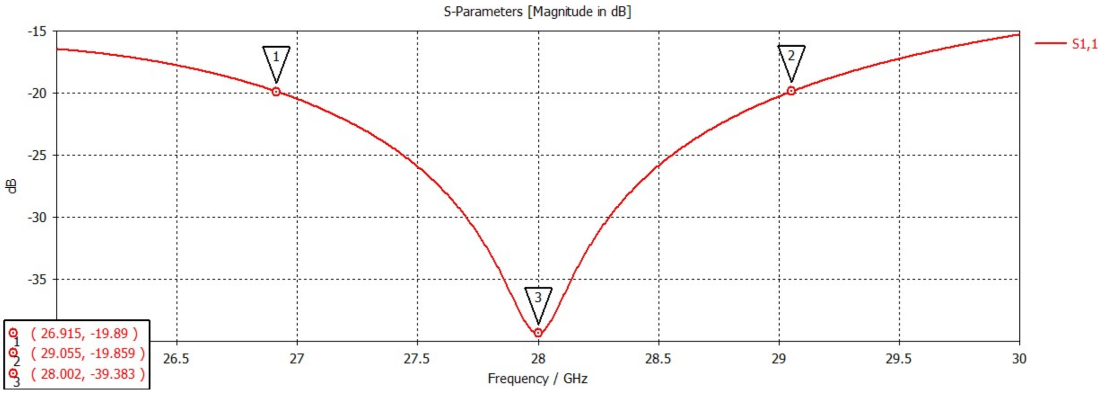


FIGURE 4.14: The bandwidth and S11 parameter for Co-Planar Parasitic Patch

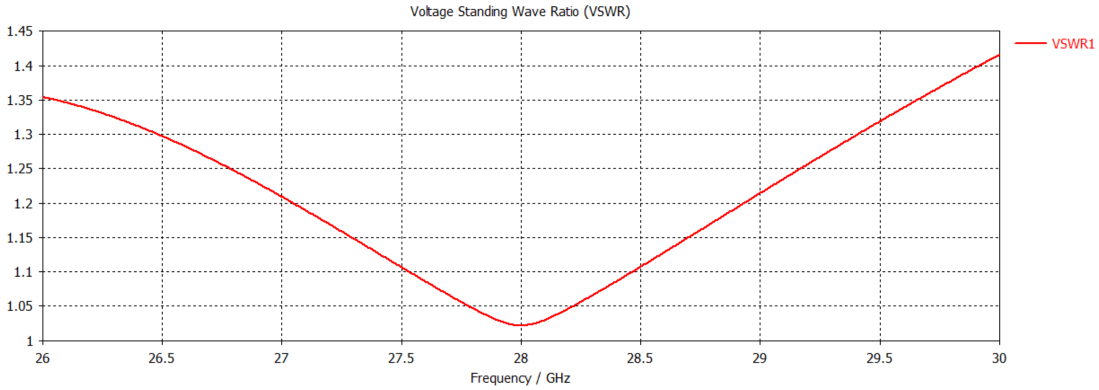


FIGURE 4.15: The VSWR for the Co-Planar Parasitic Patch

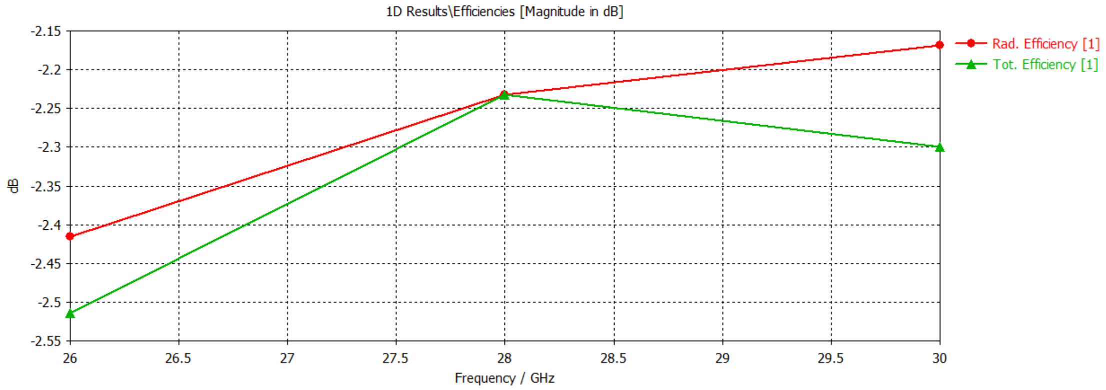
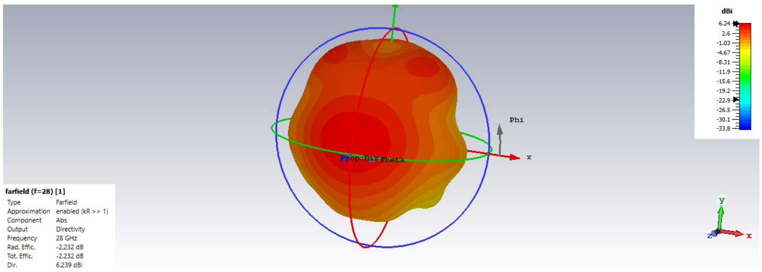
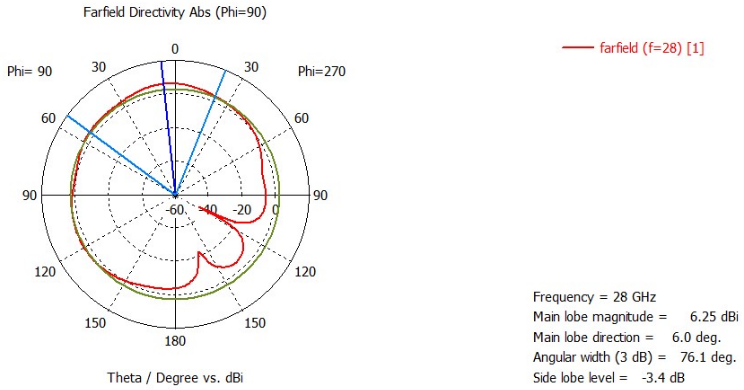


FIGURE 4.16: The efficiency for the Co-Planar Parasitic Patch



farfield (f=28) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 28 GHz
Rad. Effic. -2.232 dB
Tot. Effic. -2.232 dB
Dir. 6.239 dBi

FIGURE 4.17: Radiation pattern and directivity for the Co-Planar Parasitic Patch



Frequency = 28 GHz
Main lobe magnitude = 6.25 dBi
Main lobe direction = 6.0 deg.
Angular width (3 dB) = 76.1 deg.
Side lobe level = -3.4 dB

FIGURE 4.18: Radiation pattern and directivity for the Co-Planar Parasitic Patch in polar view

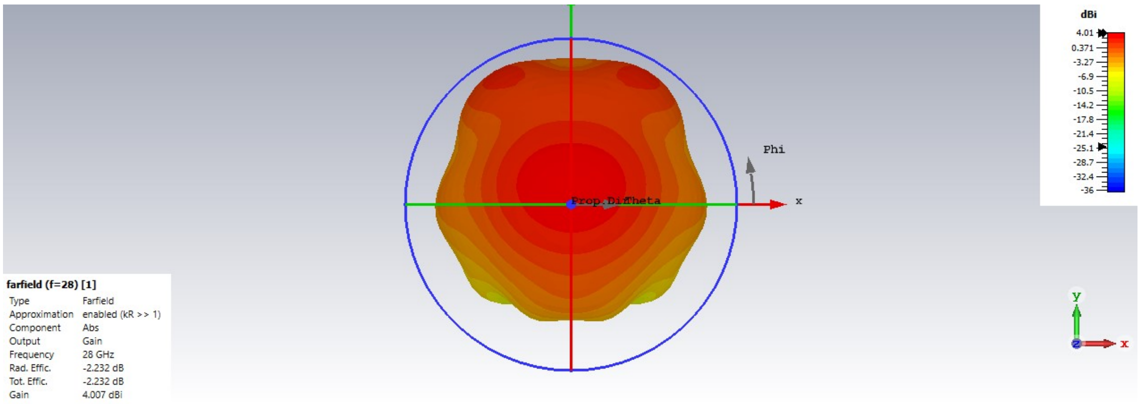


Figure 4.19: Gain and radiation pattern for the Co-Planar Parasitic Patch in three dimensions

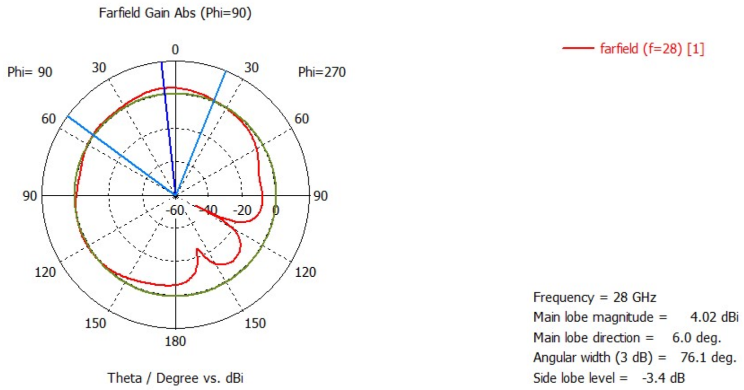


Figure 4.20: Radiation pattern and gain for the Co-Planar Parasitic Patch in polar view

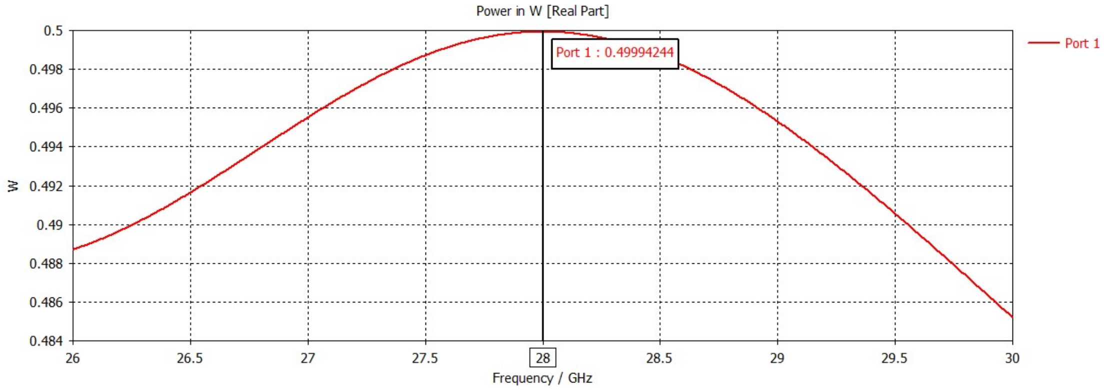


Figure 4.21: Power accepted per port for the Co-Planar Parasitic Patch

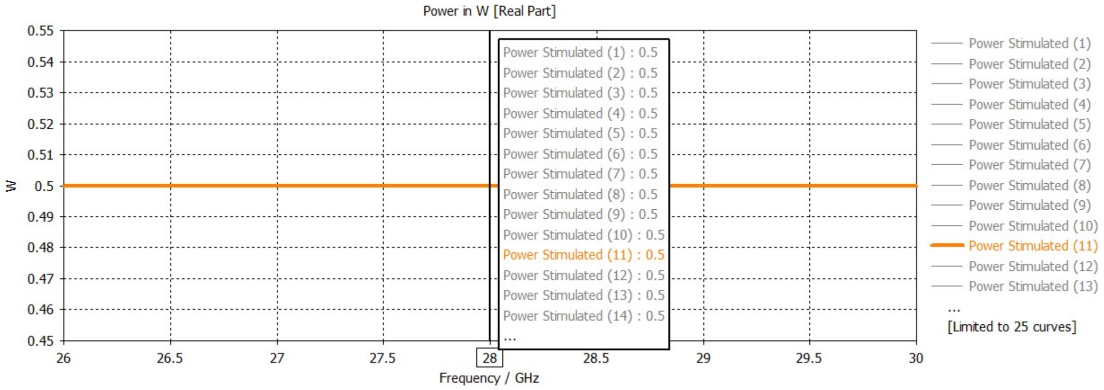


Figure 4.22: Simulated power for Co-Planar Parasitic Patch antenna

Antenna Parameters	Result/ Output
Return loss(S1,1)	-39.3887
Bandwidth	7.65%
Gain	4.007dBi
Directivity	6.239dBi
VSWR	1.021
Efficiency	64
Power Simulated	100

Table 4.2: Antenna parameter simulation results for an operating frequency of 28 GHz

In the calculated value of the designed antenna, we achieved a bandwidth of 4.38%. When we optimized the design, the bandwidth increased to 7.1%, resulting in an enhancement of approximately 62.33%. By employing the stacked parasitic patch technique, the bandwidth further improved to 7.57%, which is an enhancement of about 3.4% compared to the optimized design. Finally, using the coplanar parasitic patch technique, the bandwidth increased to 7.64%, representing an additional enhancement of 0.92% over the stacked parasitic patch technique.

4.2 Comparison

Enhancement from the Calculated Value to the Coplanar Parasitic Patch

- Calculated bandwidth: 4.38%
- Coplanar parasitic patch bandwidth: 7.64%
- Enhancement $= \frac{(7.64-4.38)}{4.38} \times 100$

$$\text{Enhancement} = \frac{3.26}{4.38} \times 100 = 74.43\% \tag{4.1}$$

Enhancement from the Optimized Value to the Coplanar Parasitic Patch

- Optimized bandwidth: 7.1%
- Coplanar parasitic patch bandwidth: 7.64%
- Enhancement $= \frac{(7.64-7.1)}{7.1} \times 100$

$$\text{Enhancement} = \frac{0.54}{7.1} \times 100 = 7.61\% \tag{4.2}$$

Final Results:

- From Calculated to Coplanar Parasitic Patch: 74.43
- From Optimized to Coplanar Parasitic Patch: 7.61

Enhancement from the Calculated Value to the Stacked Parasitic Patch

- Calculated bandwidth: 4.38%
- Stacked parasitic patch bandwidth: 7.57%
- Enhancement = $\frac{(7.57-4.38)}{4.38} \times 100$

$$\text{Enhancement} = \frac{3.19}{4.38} \times 100 = 72.83\% \tag{4.3}$$

Enhancement from the Optimized Value to the Stacked Parasitic Patch

- Optimized bandwidth: 7.1%
- Stacked parasitic patch bandwidth: 7.57%
- Enhancement = $\frac{(7.57-7.1)}{7.1} \times 100$

$$\text{Enhancement} = \frac{0.47}{7.1} \times 100 = 6.62\% \tag{4.4}$$

Enhancement from the Stacked Parasitic Patch to the Coplanar Parasitic Patch

- Stacked parasitic patch bandwidth: 7.57%
- Coplanar parasitic patch bandwidth: 7.64%
- Enhancement = $\frac{(7.64-7.57)}{7.57} \times 100$

$$\text{Enhancement} = \frac{0.07}{7.57} \times 100 = 0.92\% \tag{4.5}$$

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

Increasing the antenna's width, length, and the number of parasitic patches significantly enhances bandwidth by improving coupling and impedance matching. However, these adjustments come at the cost of reduced efficiency and increased antenna size. Among the two techniques—stacked parasitic patches and coplanar parasitic patches—stacked configurations typically require larger patch dimensions for the parasitic elements, which further increases antenna size. To overcome the challenges of antenna bulkiness while achieving optimal bandwidth, it is recommended to use coplanar parasitic patches, as they offer a more compact design with efficient performance.

In summary, we conclude that this thesis bridges the gap between current antenna technologies and the evolving needs of 5G networks, providing a cutting-edge solution that exceeds the stringent requirements of 5G communication systems.

5.2 Recommendations and Future Work

Future work on this thesis can explore several areas to enhance the antenna design. First, experimental validation should be conducted by testing the antenna in real-world conditions to confirm the simulation results. This could involve creating prototypes and performing tests in lab settings or field trials. Additionally, advanced optimization techniques, such as genetic algorithms or machine learning, can help refine the design parameters for better performance in areas like bandwidth, return loss, and VSWR. Researchers could also look into extending the frequency range of the antenna to cover more 5G bands, or even beyond, by exploring new materials or design structures.

Further improvements could include miniaturization to reduce the antenna's size while maintaining its performance, using techniques like metamaterials or fractal geometries for compact designs. Additionally, researchers should work on improving antenna efficiency, reducing losses, and enhancing power handling. This could involve optimizing impedance matching and minimizing radiation pattern distortions. By exploring these recommendations, researchers can advance microstrip patch antennas for 5G networks, contributing to the development of more efficient, reliable, and high-performance solutions for future wireless communication systems.Finally, it is recommended to develop practical infrastructure of the above designed antenna systems.

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