

# **Bandwidth and Gain Improvement of Microstrip Patch Antenna Design at 5.8 GHz Using Defected Ground Structure Technique**

A Project report is submitted in partial fulfillment of the requirements for the Award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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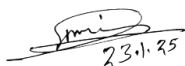


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## DECLARATION

I confirm that the project called "**Bandwidth and Gain Improvement of Microstrip Patch Antenna Design at 5.8 GHz Using Defected Ground Structure Technique**" is my own work done at Daffodil International University. It's part of my studies for a Bachelor's degree in Electrical and Electronic Engineering. This project is original and hasn't been submitted anywhere else. I've considered the possible risks, got the required ethical and safety approvals, and recognized my duties and the rights of everyone involved.

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## **APPROVAL**

The project and thesis entitled “**Bandwidth and Gain Improvement of Microstrip Patch Antenna Design at 5.8 GHz Using Defected Ground Structure Technique**” submitted by

Session: Fall 2020 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **June, 2024**.



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*Dedicated to*  
*Our Father & Mother,*

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## LIST OF ABBREVIATIONS

IEEE	Institute of Electrical and Electronic Engineers
WLAN	Wireless Local Area Network
MU-MIMO	Multi-user multiple-input multiple-output
Kbps	Kilo bites per seconds
TDMA	Time division multiple access
SIR	Signal-to-interference Ratio
Wi-Fi	Wireless Fidelity
RF	Radio Frequency
IoT	Internet of thing
OFDMA	Orthogonal frequency division multiple access
LTE	Long Term Evolution
G	Generation
GSM	Global System for Mobile communication
WPT	Wireless power transfer
ML	Machine Learning
AI	Artificial Intelligence
D	Dimension
CST	Computer Simulator Technology
VSWR	Voltage Standing Wave Ratio
UI	User Interference
MATLAB	Matrix Laboratory

## LIST OF SYMBOLS

Hz	Hertz
KHz	Kilo Hertz
MHz	Mega Hertz
GHz	Giga Hertz
mm	Millimeter
cm	Centimeter
m	Meter
$\epsilon$	Relative permittivity
L	Length
W	Width
C	Speed of light
dB	Decibel
$\lambda$	Lambda
$\Omega$	Ohm
$\epsilon_r$	Dielectric Constant

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## Abstract

This thesis focuses on improving the effectiveness and appearance of a small antenna used in modern wireless communication networks operating at 5.8 GHz. This antenna we design DGS and without DGS. A Defected Ground Structure (DGS) is a modification to the ground plane of an antenna. It involves introducing periodic or non-periodic defects (such as slots, etched patterns, or resonators) in the ground plane and an antenna without DGS typically has a simple, solid ground plane. Key performance metrics, such as S-parameters, bandwidth, VSWR, directivity, gain, radiation patterns, and radiation efficiency, are evaluated through comprehensive CST simulations. The results highlight favorable performance characteristics, including return loss values of -31.64 dB with DGS and -34.55 dB without DGS, indicating efficient power transfer and strong impedance matching. The achieved bandwidths of 240.9 MHz with DGS and 215.1 MHz without DGS surpass typical requirements for wireless communication systems, suggesting excellent performance and potential for future frequency expansion. The antenna is designed to address the need for high-speed data transmission in Bluetooth, Wi-Fi, and other wireless technologies. By addressing issues related to size, bandwidth, and signal strength, the proposed antenna aims to optimize performance for small and lightweight devices. The research project begins with a thorough analysis of existing studies, examining different materials, feeding methods, and antenna designs. Advanced tools are used to simulate and analyze the antenna's design and important characteristics like radiation pattern, bandwidth, and signal loss. The proposed antenna shows promising applications in Internet of Things (IoT) devices, wireless communication systems, and other emerging technologies that rely on stable high-frequency connections. This thesis provides valuable insights for researchers, engineers, and professionals working in antenna design and wireless communication.

**Keywords:** WLAN, Smart antennas, Deep learning-based antenna, Antenna design optimization, Reconfigurable antenna, Wireless communication.

# CHAPTER 1

## 1.1 Introduction

Wireless communication systems are rapidly evolving to meet the growing demands for high-speed, reliable, and cost-effective connectivity. Among these, Wireless Local Area Networks (WLANs) have gained significant importance due to their widespread use in mobile communication networks. The 5.8 GHz frequency band, part of the unlicensed Industrial, Scientific, and Medical (ISM) spectrum, has emerged as a promising candidate for future WLAN applications, providing higher data rates and reduced interference compared to lower-frequency bands. Microstrip patch antennas have become a preferred choice for such applications due to their low profile, lightweight structure, ease of fabrication, and compatibility with planar and non-planar surfaces. Despite these advantages, designing an efficient microstrip patch antenna for single-band operation at 5.8 GHz poses several challenges, including maintaining compact size, ensuring robust performance, and achieving a cost-effective design for mass deployment. This paper presents a novel microstrip patch antenna design specifically optimized for single-band operation at 5.8 GHz. The proposed design addresses the increasing demand for cost-effective wireless communication solutions while meeting the performance requirements of future WLAN mobile communication networks. By leveraging innovative design techniques and material choices, the proposed antenna ensures optimal gain, impedance matching, and radiation efficiency, making it a suitable candidate for next-generation WLAN applications. The following sections discuss the design methodology, simulation results, fabrication process, and experimental validation of the proposed antenna. Comparative analyses with existing designs highlight the proposed antenna's superiority in terms of performance and cost-effectiveness, making a strong case for its integration into future WLAN systems.

## 1.2 Problem Statement and Proposed solution

### 1.2.1 Problem Statement

The rapid growth of wireless communication, particularly WLAN systems, has increased the demand for antennas capable of high-performance operation in higher frequency bands like 5.8 GHz. However, existing antenna designs often struggle to achieve the necessary combination of compactness, efficiency, and cost-effectiveness for widespread deployment. Designing a microstrip patch antenna optimized for single-band operation at 5.8 GHz presents specific challenges. These include achieving stable impedance matching, adequate gain, and efficient radiation patterns while ensuring compatibility with compact devices and reducing interference in crowded wireless environments. Additionally, many current antennas design for 5.8 GHz operation rely on expensive materials or complex structures, limiting their feasibility for mass production and consumer-grade applications. The lack of cost-effective solutions tailored for future WLAN communication networks hinders their adoption, emphasizing the need for innovative antenna designs that balance high performance, scalability, and affordability.

### **1.2.2 Proposed Solution**

This paper presents a novel microstrip patch antenna design optimized for single-band operation at 5.8 GHz, addressing the growing demands of future WLAN mobile communication networks. The proposed design ensures high gain, efficient radiation, and stable impedance matching, achieved through precise patch geometry and feed structure optimization. Emphasis is placed on using cost-effective materials and simple fabrication methods, making the design suitable for large-scale deployment. By balancing performance, compactness, and affordability, the antenna effectively supports high-speed, interference-free communication. Simulation and experimental validation demonstrate its superiority over existing designs, making it an ideal solution for next generation WLAN applications.

### **1.3 Objectives**

The objective of designing a 5.8 GHz antenna is to create a high-performance antenna capable of efficiently transmitting and receiving signals within the specified frequency band. The design aims to optimize key parameters such as gain, directivity, bandwidth, and impedance matching to ensure minimal signal loss and high efficiency. This antenna must support applications in wireless communication, such as Wi-Fi, radar, and IoT devices, where stable and reliable signal transmission is crucial. Additionally, the design should focus on compactness, manufacturability, and cost-effectiveness while maintaining high performance, ensuring the antenna performs effectively in real-world scenarios under varying environmental conditions.

#### **1.3.1 Primary Objectives**

##### **1. Design a Compact Microstrip Patch Antenna:**

To design a compact microstrip patch antenna at 5.8 GHz for WLAN mobile communication networks, a triangular patch structure is proposed. The patch is designed using a lightweight substrate with FR4 ( $\epsilon_r \approx 4.4$ ) with a thickness of 1.6 mm to balance size and performance. The antenna dimensions are calculated based on the resonant frequency using the transmission line model. A microstrip feed line is employed for impedance matching, ensuring  $S_{11} < -10$  dB. The design optimizes the patch size, feed location, and ground plane to achieve high gain, efficient radiation, and compactness, meeting the demands of next-generation WLAN networks.

##### **2. Achieved resonance frequency at 5.8 GHz:**

Design a compact microstrip patch antenna resonating at 5.8 GHz for WLAN applications. Achieve optimal impedance matching with a return loss ( $S_{11}$ ) below -10 dB. Ensure high gain and efficient radiation for robust wireless communication. Minimize the antenna size while maintaining performance. Use cost-effective materials and simple fabrication techniques for scalability. Validate performance through simulation and experimental analysis to meet WLAN network demands.

##### **3. Maintain positive gain:**

Design a compact microstrip patch antenna resonating at 5.8 GHz with a focus on achieving positive gain for efficient signal transmission. Ensure stable radiation patterns and high directivity to support WLAN applications. Optimize the patch geometry and feed structure to maintain consistent positive gain across the operating frequency. Utilize cost-effective materials and scalable fabrication methods for practical implementation. Validate the antenna's performance through simulation and experimental testing to meet the requirements of next-generation wireless communication networks.

### **1.3.2 Secondary Objectives**

#### **1. Optimize Bandwidth:**

Enhance the antenna's bandwidth to support stable and reliable communication within the 5.8 GHz frequency band, ensuring minimal signal loss and improved connectivity.

#### **2. Minimize Return Loss:**

Achieve a return loss (S11) below -10 dB to ensure efficient impedance matching and reduced power reflection.

#### **3. Improve Radiation Efficiency:**

Maximize radiation efficiency to ensure effective signal transmission and reception.

#### **4. Compact Design:**

Maintain a compact and lightweight structure suitable for integration into WLAN mobile devices.

#### **5. Cost-Effective Implementation:**

Use affordable materials and straightforward fabrication techniques for scalability and mass production.

#### **6. Environmental Suitability:**

Design for robust performance under varying environmental conditions, ensuring reliability in real-world applications.

#### **7. Validation and Testing:**

Validate the design through simulation and experimental testing to confirm adherence to performance objectives.

### **1.4 Brief Methodology**

The 5.8 GHz antenna design involves selecting an appropriate antenna type (e.g., microstrip patch, dipole), calculating dimensions based on the wavelength ( $\lambda$ ), and optimizing parameters like resonance, bandwidth, and gain. Simulation tools (e.g., HFSS, CST) are used for performance analysis, followed by fabrication and testing for real-world validation.

#### **1. Antenna Design and Simulation:**

The design begins by selecting a suitable substrate (e.g., FR4) and calculating the dimensions of the rectangular microstrip patch using the transmission line model. The patch and feed line dimensions are optimized to achieve a resonance frequency of 5.8

GHz. Simulation software CST is used to model and fine-tune the design for impedance matching, bandwidth, and gain.

#### 2. Optimization:

The antenna's parameters (patch size, feed position, and ground plane dimensions) are iteratively adjusted to optimize bandwidth, minimize return loss ( $S_{11} < -10$  dB), and maintain positive gain.

#### 3. Fabrication:

Fabricating a 5.8 GHz microstrip patch antenna involves designing the patch dimensions using a substrate with appropriate permittivity, typically FR4 or Rogers. Use photolithography or CNC milling to etch the patch and ground plane. Connect the feed line, test impedance matching, and optimize for WLAN single-band performance using simulation tools CST.

#### 4. Experimental Validation:

Experimental validation of a 5.8 GHz microstrip patch antenna involves measuring key parameters using a vector network analyzer (VNA) to assess return loss, impedance matching, and resonant frequency. Test radiation patterns and gain in an anechoic chamber. Compare results with simulations to ensure alignment and refine design as needed.

#### 5. Performance Analysis:

Final performance metrics such as gain, efficiency, and radiation pattern are analyzed to ensure the antenna meets the objectives for WLAN communication.

## 1.5 Thesis Organization

The thesis having seven chapters. Those chapter carries particular discussion about introduction, procedures, simulation, results etc.

**Chapter 1** provides an overview of the thesis, outlining the background and summarizing the problems to be addressed as well as the objectives of the study. It also details the methodology for implementation and the process of implementation.

**Chapter 2** delves into a comprehensive literature review, identifying research gaps and comparing the current work with existing literature. This chapter highlights the uniqueness of the proposed work compared to previous studies, aiming to identify the best approach to achieving the goals of the thesis.

**Chapter 3** focuses on the materials and methodology employed for the specific antenna design and other techniques utilized in the system. It elaborates on the design process, various antenna parameters, and system analysis conducted through simulations.

**Chapter 4** presents the results obtained from the project simulations and discusses their implications. It examines the findings throughout the thesis and analyzes their impact on the overall project objectives and related terms.

**Chapter 5** addresses project management aspects, including time scheduling, cost management, and resource allocation required for the implementation of the project. It evaluates the cost-effectiveness of necessary resources.

**Chapter 6** evaluates the impact of the project, both locally and globally, including ethical and environmental considerations. Safety issues, applications of the project, and its potential impact on society are discussed in this section.

**Chapter 7** provides the final discussion, offering insights into potential improvements for the system and recommendations for future researchers. It also explores new features that could be incorporated into the system in future studies, concluding with a summary of future research directions.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

This chapter presents a thorough investigation and evaluation of current research in the field of DGS included in antenna design for performance improvement. This document conducts a thorough literature review and comparative analysis to highlight important trends, advancements, and research gaps in the field, with the goal of guiding the creation of innovative antenna designs tailored for WLAN applications.

### 2.2 Related Research Works

CST Studio Suite, Ansys HFSS, and MATLAB PCB Antenna Designer are advanced electromagnetic simulation tools used for designing, analyzing, and optimizing RF components and systems. These programs employ sophisticated computational techniques, such as finite difference and finite element methods, to accurately calculate key antenna parameters like reflection coefficient, gain, bandwidth, and VSWR. They enable engineers and researchers to model electromagnetic phenomena, study antenna behavior, and refine designs for optimal performance. These platforms are essential for antenna designers, supporting the development of innovative, high-performance RF solutions for a wide range of applications [1].

Many filters have been investigated which controls the centre frequency and bandwidth. DGS based patterns that can be considered the dual of the open-loop microstrip resonators is proposed in and used to design coupled resonator filters with different external coupling arrangements. The same concept has also been used to design a multilayer coupled resonator DGS filter. This approach introduces various coupling mechanisms to achieve a wider class of filtering functions. Dual-band bandpass filters featuring compact size and flexible frequency choice are demonstrated in using resonators based on slotted ground structures [2]. Two resonators based on slotted ground structures form the basis of the filter design. The resonators allow the back-to-back and face-to-face embedding configuration, hence, greatly reduces the physical size of the filters. The work reported in proposed bandpass filter design based on coupled DGS and microstrip resonators [3]. The combination of DGS and microstrip resonators allows use of the top and bottom side of the microwave substrate, therefore the resonators can partially overlap and desired coupling coefficient can be achieved [4].

A defected ground structure (DGS) can be used in patch antenna design to reduce the size of the antenna, increase the bandwidth, and improve gain by modifying the electromagnetic (EM) field distribution between the patch and the ground [5] For designing a wearable antenna, the substrate and supporting layers must be made of a dielectric material, while the radiating elements such as patches, feeding lines, and

ground plane must be made of conducting materials. These dielectric and conducting materials have been carefully chosen to provide an acceptable level of mechanical distortion while also being resistant to the effects of temperature, humidity, and radiation from electromagnetic fields. As a result, the wearable antenna will guarantee the user's comfort and security [6]. To fabricate the integrated antenna, polydimethylsiloxane (PDMS) was used for the sub-strate, and silver nanowires (AgNWs) were used for the conducting materials. The presence of meta surface provided a gain of 5.2 dB, a 3-dB axial ratio (AR) BW of 69 MHz, and an FBR of 16 db. Furthermore, the presence of meta surface provided stable performance due to deforming and human body loading. A very low SAR of 0.13 W/Kg under a 1 g standard was obtained [7].

The antenna design is created to operate across two frequency ranges: 5.8 GHz for Wi-Fi applications and between 6 GHz to 8 GHz for 5G mobile applications. It features a hexagonal shape with five surrounding hexagonal metamaterials, as developed by [8]. To achieve a compact size for a printed inverted F-shaped MIMO antenna working at 5.8 GHz for Wi-Fi, the design incorporates a short-circuited fractal-shaped patch at one end. This innovation helps reduce the overall size of the antenna while maintaining performance across the desired frequency bands.

The Wireless Local Area Network (WLAN) is a widely used method for building wireless networks. WLAN typically operates on two frequency bands: the 2.4 GHz band (ranging from 2.4 to 2.484 GHz) and the 5.8 GHz band (ranging from 5.725 to 5.825 GHz). However, the 2.4 GHz band is becoming increasingly congested due to the growing demand for wireless communication. As a result, many users are shifting to the 5.8 GHz band, which offers more available spectrum and experiences less interference [9].

These studies collectively contribute to the ongoing advancement of antenna technologies for WLAN communication systems, presenting a variety of designs optimized for improved performance across single-band frequencies essential for WLAN applications. These innovations help enhance connectivity and efficiency within the specific frequency ranges used by WLAN networks.

### 2.3 Compare and Contrast

It looks like about to compare the performance of our antenna with others listed in a table. We provide the details from **Table 4.1**, such as performance metrics or key specifications (like gain, bandwidth, efficiency, size, etc.), we can help summarize the comparison or provide insights on how our antenna stands relative to the others.

**Return Loss:** Our design demonstrates favourable return loss values at both frequencies, comparable to the performance in Ref [10], but performs better than Ref. [11] at the 5.8 GHz band, exhibiting a lower return loss.

**Bandwidth:** Our design offers a wider bandwidth at 5.8 GHz than most other designs [12], [13].

**GAIN:** Our design 5.8 GHz achieves high gain at both frequencies compared to other designs Ref [14].

Overall, our design delivers strong performance in return loss, bandwidth, and directivity for a single-element antenna operating at 5.8GHz. It strikes a balanced approach, optimizing these key metrics without focusing excessively on any one aspect.

### **Gap 1: Achieving wider bandwidth while maintaining good return loss**

The design achieves a reasonable bandwidth, especially at 5.8 GHz, but existing research has shown antennas with broader bandwidths. To enhance the design, it is suggested to explore optimization methods, such as adding more slots to the antenna structure or combining different shapes (e.g., triangular patch with a slot) and applying the DGS technique. These improvements could help achieve a wider bandwidth while maintaining good signal reflection (return loss) at the target frequencies.

### **Gap 2: Single - functional antenna designs**

Single-functional antenna designs are antennas that are optimized for operation in a specific frequency band or for a particular application. These designs typically focus on achieving high performance for a single purpose, such as maximizing gain, minimizing signal interference, or ensuring good impedance matching within a specific frequency range. The simplicity and efficiency of single-functional antennas make them ideal for many traditional wireless communication systems, radar applications, and other specialized technologies where narrowband operation is sufficient.

### **Gap 3: Fabrication considerations**

The design shows good performance in simulations, but manufacturability needs further attention. Challenges related to fabrication precision and material limitations have not been fully considered. A manufacturability analysis is recommended to identify potential production difficulties, such as tight tolerances or high material costs. Exploring simpler fabrication methods or alternative materials could help achieve the same performance while making the design more cost-effective and scalable for mass production.

### **Additional Considerations:**

To ensure optimal performance, the antenna must be evaluated for compatibility with existing or planned WLAN communication systems, including protocols and signal formats. Additionally, for wearable applications, the impact of the human body on the

antenna's functionality needs to be considered. Studies on how the body absorbs and reflects radio waves at relevant frequencies will be important, as adjustments to the design may be necessary to maintain performance and radiation patterns when worn.

## **2.4 Summary**

In this chapter we have reviewed the literature on single-band antenna designs specifically suited for WLAN communication systems. Identifying trends, evaluating current designs, and pointing out research gaps in the sector were our goals. We looked at research on a range of antenna types, such as frequency-reconfigurable antennas, substrate integrated waveguide antennas, antenna arrays, and microstrip patch antennas. We evaluated these designs' performance measures, comprising bandwidth, gain, and return loss, applying comparative analysis. We analyzed the strengths and weaknesses of each design and offered recommendations for enhancement.

In summary, this chapter offers valuable insights into the current advancements in single-band antenna design for WLAN networks, providing a foundation for future research and development in this field.

# CHAPTER 3

## METHODOLOGY AND METHODS

### 3.1 Introduction

The design of a 5.8 GHz single-band microstrip patch antenna for WLAN systems involves a systematic approach that includes selecting the appropriate antenna geometry, substrate material, and feeding techniques, as well as performing detailed simulations and optimizations to achieve desired performance characteristics. The methodology focuses on ensuring that the antenna meets key WLAN requirements such as bandwidth, gain, impedance matching, and radiation efficiency. Additionally, advanced techniques like Defected Ground Structures (DGS) can be explored to further enhance antenna performance.

The first step in the methodology is the selection of the antenna structure. For WLAN systems operating in the 5.8 GHz frequency band, a microstrip patch antenna is chosen due to its compactness, ease of fabrication, and integration with modern printed circuit board (PCB) technology. The patch dimensions, substrate material, and feed configuration are then determined based on the desired resonant frequency, impedance, and radiation pattern.

Next, the substrate material is selected to meet the necessary requirements for low loss, high efficiency, and low dielectric constant. Materials like Fr4 are commonly chosen for their low loss tangent and good dielectric properties at high frequencies. The substrate thickness and relative permittivity ( $\epsilon_r$ ) are optimized to achieve wide bandwidth and efficient radiation. Once the basic geometry is defined, the antenna is simulated using advanced computational tools such as CST Microwave Studio. These tools are employed to model the antenna's electromagnetic behavior, analyze the input impedance, return loss ( $S_{11}$ ), and radiation pattern, and identify areas for optimization. The feeding mechanism is then selected, with options like microstrip line feed, coaxial feed, or aperture coupling. The feed design ensures that the antenna operates efficiently within the 5.8 GHz band while minimizing return loss and maximizing power transfer. For performance enhancement, especially for bandwidth and impedance matching, Defected Ground Structures (DGS) can be incorporated into the design. DGS involves introducing intentional slots or patterns into the ground plane to improve the antenna's impedance characteristics and suppress surface wave losses, leading to better bandwidth and overall performance. The final step in the methodology involves performance validation. After the design is optimized through simulation, the antenna prototype is fabricated and tested. Parameters like return loss, gain, efficiency, and radiation pattern are measured and compared with the simulated results to confirm the antenna's performance in a real-world environment.

This methodology ensures the systematic design, analysis, and optimization of a 5.8 GHz microstrip patch antenna that meets the stringent requirements of modern WLAN

systems, offering high performance in terms of bandwidth, efficiency, and cost-effectiveness.

## 3.2 Overview of an Antenna

A microstrip patch antenna is a widely used antenna type for wireless communication systems, including WLAN applications, due to its compact size and ease of fabrication. It consists of a radiating patch, dielectric substrate, and ground plane. The antenna can be fed through microstrip lines, coaxial cables, or aperture coupling. Without Defected Ground Structures (DGS), the antenna provides basic performance with limited bandwidth and efficiency. However, incorporating DGS—geometric defects in the ground plane enhances performance by improving impedance matching, reducing surface wave losses, and widening the bandwidth. This makes DGS-based antennas more suitable for high-performance WLAN applications like 5.8 GHz systems.

### 3.2.1 Different Types of an Antenna

There are various types of antennas, each designed to meet specific requirements for different applications, ranging from wireless communication to radar and broadcasting. Below are some of the most common types of antennas:

#### Microstrip Patch Antenna

A microstrip patch antenna is a type of antenna consisting of a thin, flat conducting patch mounted on a dielectric substrate with a ground plane on the opposite side. It is widely used due to its low profile, lightweight design, and ease of integration into electronic systems, especially in mobile devices, satellites, and IoT applications. Microstrip patch antennas offer relatively narrow bandwidth but can be optimized for specific frequencies. They are simple to fabricate using PCB techniques and provide moderate gain and directivity. However, their efficiency can be affected by the choice of substrate material and feed configuration.

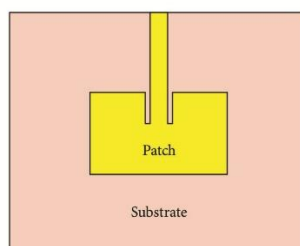


Fig 3.1: Microstrip Patch Antenna

## Dipole Antenna

A dipole antenna is one of the simplest and most widely used types of antennas, consisting of two conductive elements, typically in the shape of a straight line, that are fed with an alternating current at the center. It is known for its omnidirectional radiation pattern in the horizontal plane, making it ideal for general-purpose communication applications. The antenna's length is usually half of the wavelength of the frequency it is designed to operate at. Dipole antennas offer broadband performance and are relatively easy to construct and tune. However, their physical size can be a limitation for lower-frequency applications.



Fig 3.2: Dipole Antenna

## Monopole Antenna

A monopole antenna is a type of antenna that consists of a single conducting element, typically mounted above a ground plane, which acts as a reflective surface. It is similar to a dipole antenna, but only one half of the dipole is used, with the ground plane serving as the other half. Monopole antennas are known for their omnidirectional radiation pattern, making them suitable for applications like mobile communications and broadcasting. They are compact, easy to design, and integrate well into devices. However, their performance is highly dependent on the quality and size of the ground plane.



Fig 3.3: Monopole Antenna

## Yagi-Uda Antenna

The Yagi-Uda antenna is a directional antenna consisting of a main radiating element (driven element), a reflector, and one or more directors. It is known for its high gain and narrow beam width, making it ideal for applications requiring focused, long-range communication, such as in television reception and amateur radio. The reflector is placed behind the driven element, while the directors are positioned in front to enhance the radiation in a specific direction. Yagi-Uda antennas are relatively simple to construct and offer good performance, but their size and directivity can limit their use in certain applications.



Fig 3.4 : Yagi-Uda Antenna

## Patch Antenna with Defected Ground Structure (DGS)

A patch antenna with Defected Ground Structure (DGS) is an advanced version of the traditional patch antenna, where a pattern of defects or slots is introduced into the ground plane. These defects help improve the antenna's bandwidth, impedance matching, and radiation efficiency. DGS can also enhance the antenna's gain and selectivity by modifying the current distribution on the ground plane, which in turn affects the radiation pattern. This design is particularly useful in applications requiring compact size and high-performance antennas, such as in wireless communication and IoT systems. However, the complexity of integrating DGS requires careful design to avoid unwanted effects like increased loss or reduced efficiency.

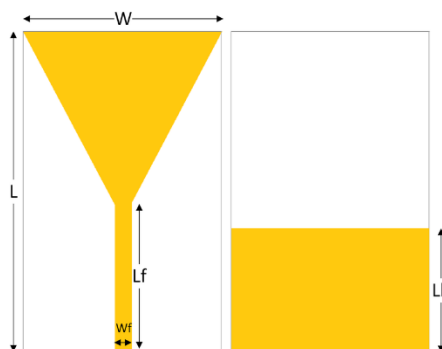


Fig 3.5 : Patch Antenna with Defected Ground Structure (DGS)

## Spiral Antenna

A spiral antenna is a type of broadband antenna that consists of one or more conductive spiral-shaped structures. It is known for its wideband performance and the ability to produce circular polarization over a broad frequency range. Spiral antennas are often used in applications requiring wide coverage, such as satellite communication, radar systems, and electronic warfare. They offer high efficiency, compact design, and good impedance matching across a wide range of frequencies. However, their complexity and relatively larger size compared to other antennas may limit their use in some applications.

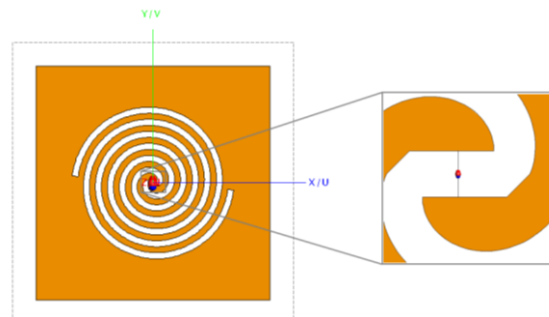


Fig 3.6 : Spiral Antenna

## Helical Antenna

A helical antenna consists of a conducting wire wound in the shape of a helix, typically mounted above a ground plane. It is known for producing circular polarization, which is ideal for satellite communication, GPS, and deep-space applications. Helical antennas offer wide bandwidth and high gain, making them suitable for long-range communication. They can be designed in either monopole or dipole configurations. However, they are relatively large compared to other antennas and require precise alignment to ensure optimal performance.



Fig 3.7 : Helical Antenna

### 3.2.2 Radiation Pattern

The radiation pattern of an antenna is a graphical representation that shows how the antenna radiates energy in space, varying with the angle. It illustrates the intensity of radiation in different directions, helping to understand the antenna's directivity, gain, and efficiency. Radiation patterns are crucial for designing antennas to meet specific application requirements, such as coverage and interference minimization. The main lobe represents the direction in which the antenna radiates the most power, while the side lobes and back lobes show unwanted radiations in other directions. Nulls are points where the radiation intensity is zero, indicating directions where the antenna does not radiate. The beam width, defined as the angular width between the half-power points (3 dB points) of the main lobe, indicates the focus of the antenna's radiation. A narrow beam width corresponds to high directivity and gain. Radiation patterns are classified into types based on their shape, such as omnidirectional, where the radiation is uniform in all directions (e.g., monopole antennas), and directional, where radiation is concentrated in specific directions (e.g., Yagi-Uda or parabolic dish antennas). Bidirectional patterns radiate energy in two opposite directions, while cardioid and conical patterns offer more focused, specific radiation areas. Understanding radiation patterns is vital for designing efficient antennas that optimize signal coverage and minimize interference, particularly in systems like WLAN, satellite, and radar communications.

### 3.2.3 Gain of Antenna

The gain of an antenna measures how effectively it radiates power in a specific direction compared to a reference antenna, such as an isotropic radiator. It is expressed in decibels (dB) and combines two factors: directivity (the concentration of radiation in a particular direction) and efficiency (how much input power is radiated versus lost). Higher gain indicates better focusing of radiated energy, making it ideal for long-range communication and directional applications.

Antenna gain is frequency-dependent and is influenced by the antenna's design, size, and shape. For example, a 5.8 GHz patch antenna offers moderate gain, suitable for applications like Wi-Fi or IoT. The gain is typically calculated using the formula:

$$G = \frac{4\pi A}{\lambda^2}$$

where  $A$  is the effective aperture and  $\lambda$  is the wavelength. High gain antennas have narrower beams, providing more focused energy in specific directions.

### **3.2.4 Directivity of Antenna**

For a 5.8 GHz single-band microstrip patch antenna used in WLAN systems, the directivity plays a critical role in determining the antenna's performance. At 5.8 GHz, the antenna is designed to provide a focused radiation pattern, which enhances signal strength and coverage for WLAN communication. The directivity of such an antenna depends on factors like its geometry and beam width. Typically, a microstrip patch antenna at 5.8 GHz would have moderate directivity, with values ranging from 5 to 8 dBi, which is sufficient for WLAN applications that require good signal directionality and coverage over a local area. The directivity can be optimized by adjusting the patch's dimensions and the shape of the ground plane. A more directional radiation pattern allows for better focus on specific regions, minimizing interference and improving data transmission efficiency in high-speed WLAN networks. Therefore, directivity helps ensure that the 5.8 GHz antenna performs effectively in indoor and outdoor WLAN systems.

### **3.2.5 S- parameter for Antenna**

For a WLAN system operating at 5.8 GHz, the S-parameter primarily focuses on S11 (return loss), which measures the amount of power reflected from the antenna. To ensure efficient performance, S11 should ideally be less than -10 dB at 5.8 GHz, indicating good impedance matching and minimal signal reflection. This parameter also helps define the antenna's bandwidth, which is the frequency range over which S11 remains below -10 dB. Accurate S-parameter measurements are critical for optimizing the antenna's efficiency, gain, and radiation pattern. These measurements are typically performed using a vector network analyzer during simulation and experimental validation stages.

### **3.2.6 VSWR of Antenna**

The Voltage Standing Wave Ratio (VSWR) measures an antenna's efficiency in transmitting and receiving electromagnetic waves, reflecting how well the antenna's impedance matches the transmission line. VSWR is the ratio of the maximum forward wave amplitude to the maximum reflected wave amplitude. A VSWR of 1 signifies perfect impedance matching, ensuring efficient power transfer without reflections. Higher VSWR values indicate poor matching, leading to signal loss, reduced range, degraded quality, and more interference. Minimizing VSWR is essential for optimizing antenna performance.

### **3.2.7 Near Field & Far Field**

The ideas of near field and far field are essential to antenna design in order to comprehend how the antenna radiates and interacts with the environment. These fields have an important effect on the antenna system's performance and are specified by the distance from the antenna. An creative simulation tool called CST Microwave Studio (CST) can assist in accurately evaluating the near field and far field regions of antennas, such as the 5.8 GHz triangular patch antenna.

### **3.2.8 Antenna Efficiency**

Antenna efficiency is a measure of how effectively an antenna converts the input power into radiated electromagnetic energy. It is the ratio of the radiated power to the total input power, which includes both radiated power and power lost due to factors like resistance and imperfect materials. High efficiency means that most of the input power is radiated, resulting in stronger signals and better performance. Factors that affect antenna efficiency include material losses, mismatched impedance, and environmental influences. Antennas with low efficiency often suffer from reduced range and signal quality. To optimize antenna efficiency, designs focus on minimizing losses and ensuring proper impedance matching with the transmission line.

### **3.2.9 Input Impedance of Antenna**

In CST Microwave Studio, the input impedance of an antenna is crucial for ensuring efficient performance. The software simulates the antenna's electromagnetic behavior using methods like Finite Integration Technique (FIT) or Method of Moments (MoM). It calculates the antenna's resistive and reactive impedance components, helping designers assess the impedance match at the feed point. CST provides the reflection coefficient (S11), VSWR, and impedance characteristics, enabling designers to evaluate and optimize the antenna's performance. If needed, parameters like patch dimensions and feed placement can be adjusted to achieve optimal impedance matching for minimal power loss and maximum efficiency.

### **3.2.10 Bandwidth of Antenna**

The range of frequencies that an antenna is able to send or receive electromagnetic signals is known as its antenna bandwidth. An antenna is made for use at a specific central frequency. However, it can also work rather effectively at frequencies that are a little bit above and below the central frequency. The -10dB point at the lower cutoff frequency to the -10dB point at the higher cutoff frequency is usually how we evaluate bandwidth.

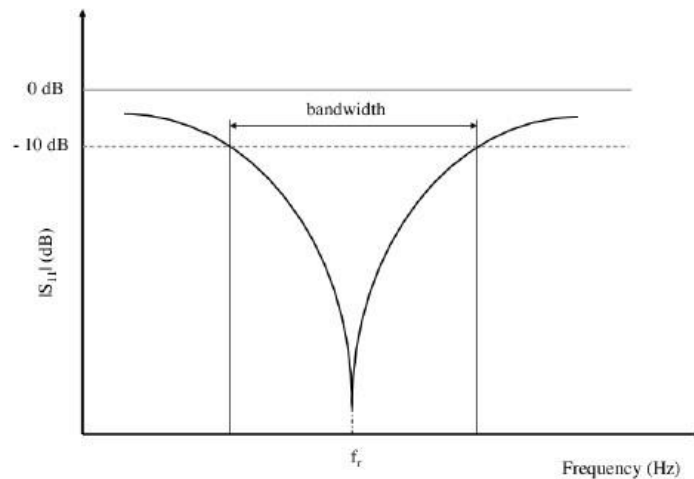


Figure 3.8 : Bandwidth Measurement

### 3.3 Methods and Materials

Methods and Materials for Designing a 5.8 GHz Microstrip Patch Antenna.

#### Antenna Design Approach:

Use the Transmission Line Model to calculate the patch dimensions (length and width) for resonance at 5.8 GHz.

Optimize the geometry using electromagnetic simulation tools such as CST Microwave Studio, HFSS, or MATLAB for fine-tuning impedance matching and gain.

#### Simulation and Analysis:

Perform simulations to analyze return loss ( $S_{11}$ ), VSWR, bandwidth, gain, and radiation pattern.

Iterate the design to meet WLAN system requirements like compact size, efficiency, and positive gain.

#### Fabrication:

Fabricate the antenna using photolithography or PCB manufacturing techniques.

Employ etching processes to create the patch and feedline on the substrate.

### **Testing and Validation:**

Use a Vector Network Analyzer (VNA) to measure S-parameters, VSWR, and bandwidth.

Test the radiation characteristics in an anechoic chamber to verify performance metrics.

### **Materials**

#### **Substrate:**

We selected FR-4 as the substrate for its low cost and widespread availability. FR-4 has a dielectric constant of 4.3, making it a practical choice for designing antennas operating at 5.8 GHz. Its moderate dielectric constant ensures good impedance matching and efficient radiation performance at this frequency. Additionally, the material's mechanical stability and ease of fabrication make it highly suitable for prototyping and mass production. While FR-4 may have slightly higher losses compared to specialized substrates, its cost-effectiveness and adequate performance make it an ideal choice for applications requiring a balance between affordability and functionality at 5.8 GHz.

#### **Conducting Layer:**

Copper or gold plating for the patch and feedline (thickness ~35  $\mu\text{m}$ ).

#### **Ground Plane:**

A conductive sheet or layer beneath the substrate to enhance radiation efficiency.

### **Feed Mechanism:**

Microstrip Line Feed: Simple and effective for impedance matching.

Coaxial Probe Feed: Offers flexibility in feed position but slightly more complex.

### **Tools and Equipment:**

- Simulation software for design optimization.
- PCB fabrication tools for etching and assembly.
- VNA and anechoic chamber for testing.

By combining accurate design methods and carefully selected materials, a high-performance 5.8 GHz antenna can be realized for WLAN applications.

### **3.3.1 Research Design**

The research design for developing a compact 5.8 GHz microstrip patch antenna focuses on a systematic approach to designing, simulating, fabricating, and validating the antenna to meet the requirements of WLAN communication networks.

### **Research Approach**

Exploratory Design: Investigate existing antenna designs and identify limitations in performance, bandwidth, and cost.

Experimental Validation: Use simulations and real-world testing to evaluate the antenna's performance.

### **Steps in the Research Design**

#### **Design and Simulation**

Use theoretical models (Transmission Line Model or Cavity Model) to calculate initial dimensions of the patch and ground plane.

Simulate the antenna design using electromagnetic software (e.g., CST Microwave Studio, HFSS).

Optimize parameters such as feed position, substrate material, and patch geometry to achieve desired performance metrics ( $S_{11} < -10$  dB,  $VSWR < 2$ , positive gain).

#### **Fabrication**

Select a suitable substrate (e.g., FR4 or Rogers RT/Duroid) and fabricate the antenna using photolithography or PCB manufacturing techniques.

#### **Testing and Validation**

Measure S-parameters, bandwidth, gain, and radiation patterns using a Vector Network Analyzer (VNA) and an anechoic chamber.

Compare experimental results with simulation data to validate performance.

#### **Data Collection and Analysis**

Collect quantitative data on return loss ( $S_{11}$ ), VSWR, gain, efficiency, and bandwidth.

Analyze the relationship between design parameters and performance to optimize the final design.

#### **Outcome**

Develop a cost-effective, compact antenna that operates efficiently at 5.8 GHz, meeting WLAN communication demands.

### **Evaluate statistical considerations for upcoming research.**

When evaluating a 5.8 GHz antenna with and without DGS, key statistical considerations include:

**Sample Size:** Ensure enough prototypes are tested for reliable comparisons.

**Variability and Repeatability:** Check consistency of parameters across multiple tests.

**Measurement Uncertainty:** Account for errors from testing equipment.

**Statistical Analysis:** Use t-tests or ANOVA to determine if performance differences are significant.

**Confidence Intervals:** Calculate intervals to assess the precision of measurements.

**Future Research:** Explore alternative DGS designs and their impact on different frequency bands

These methods ensure robust and reliable conclusions about the impact of DGS on antenna performance.

### **3.3.2 Software for research**

In this research, several software tools were used for the design, simulation, and analysis of antenna design. We used CST but different type software are :

**HFSS (High-Frequency Structure Simulator):** Used for 3D modeling and electromagnetic simulation, HFSS helped analyze key parameters like return loss, VSWR, bandwidth, and radiation patterns using its FEM solver.

**CST Microwave Studio:** This tool supported both time-domain and frequency-domain simulations, optimizing antenna dimensions and analysing radiation patterns and gain.

**ADS (Advanced Design System):** ADS facilitated the design of the antenna's transmission line and matching network, as well as simulating S-parameters and impedance matching for optimal performance.

**FEKO:** FEKO provided detailed analysis of the antenna's far-field radiation pattern and the impact of DGS on resonant frequency and bandwidth.

These software tools allowed for comprehensive simulation, design optimization, and analysis, ensuring that the antenna met performance specifications and demonstrated the advantages of DGS.

### 3.4 Design Specifications, Standards and Constraints

#### Design with DGS

The design with Defected Ground Structure (DGS) aims to enhance the antenna's performance by introducing defects (such as slots or cuts) in the ground plane. The specific design considerations for the DGS antenna include:

**Ground Defects:** The DGS antenna incorporates specific slots or cuts in the ground plane to modify the current distribution, improving impedance matching and enhancing bandwidth.

**Impact on Bandwidth:** The DGS is expected to increase the bandwidth by reducing the return loss over a wider frequency range.

**Resonant Frequency Shift:** The DGS structure may cause a slight shift in the resonant frequency, which will be compensated for during the design process to ensure resonance at 5.8 GHz.

**Size of Defects:** The size, shape, and position of the defects are carefully selected to achieve the desired performance without introducing too much complexity or affecting the antenna's compact form factor.

#### Design without DGS

The antenna design without DGS focuses on a conventional microstrip or patch antenna configuration. The primary considerations for this design include:

**Simplicity:** This design focuses on a simple, cost-effective solution without the complexity of additional ground defects.

**Impedance Matching:** Ensuring that the antenna has good impedance matching at the operating frequency to minimize signal reflection and maximize power transfer.

**Bandwidth Limitations:** Without DGS, the bandwidth of the antenna may be more limited compared to the DGS design, but efforts are made to ensure it meets the minimum bandwidth required for reliable communication at 5.8 GHz.

#### Standards and Regulatory Constraints

Both antenna designs must adhere to several key standards and regulations to ensure their compliance with industry requirements:

**IEEE Standards:** The design follows the IEEE 802.11 standards for Wi-Fi communications, which operates in the 5.8 GHz frequency range. Ensuring that the

antenna supports efficient communication within these standards is crucial for its performance.

**FCC Regulations:** The Federal Communications Commission (FCC) has regulations regarding permissible radiation levels and frequencies for devices operating in the ISM band. The antenna designs must ensure that they comply with these regulations to avoid interference with other communication systems.

**Safety Standards:** The antenna must be designed to comply with safety standards regarding radiation exposure and electromagnetic compatibility (EMC) to prevent harm to users and interference with other electronic devices.

### **Constraints**

While designing the 5.8 GHz antenna with and without DGS, several constraints were considered:

**Fabrication Limitations:** The antenna design must be feasible for fabrication using available materials and manufacturing techniques, such as PCB (printed circuit board) technology. This includes limitations on the precision of cuts and slots in the DGS design.

**Size and Form Factor:** The antenna must be compact and lightweight, especially when integrated into portable communication devices.

**Material Choices:** The choice of materials, such as FR4 (a common PCB material) and copper for conductive layers, impacts the antenna's performance, particularly in terms of loss and efficiency.

**Cost:** While the DGS design may offer improved performance, it adds complexity to the antenna structure, potentially increasing manufacturing costs. A balance between performance and cost is necessary for practical applications.

### **3.3 Design Process of Proposed Single Band Microstrip Patch Antenna**

As shown in Figure, the proposed microstrip patch antenna operates in single bands configuration. To get the ideal frequencies, these slots must be positioned carefully. The dielectric substrate is FR-4, which has a dielectric constant of 4.3 and a thickness of 1.6 mm. Standard 50  $\Omega$  microstrip feed line is used to guarantee effective power transfer. Because of its small size (25 x 25 x 1.6 mm<sup>3</sup>), the antenna is a good choice for applications where space is an issue. For best results, the radiating patch itself is made of copper that is 0.035 mm thick. The antenna is intended for dual-band operation and operates at 5.8 GHz. This microstrip patch is designed and simulated using CST Studio Suite 2022 software.

### 3.4.1 Geometrical Analysis

Geometrical analysis in 5.8 GHz antenna design involves studying the antenna's physical structure to optimize its performance for high-frequency signals. The key elements of this analysis include the shape, size, and arrangement of the antenna elements, which affect the radiation pattern, impedance, and efficiency. At 5.8 GHz, the wavelength is approximately 5.17 cm, so the antenna must be compact and precisely engineered to minimize losses and enhance directivity. Geometrical factors, such as the spacing between antenna elements and the material properties, play a critical role in achieving the desired gain and beam width. Numerical methods, like the Method of Moments (MoM) or Finite Element Method (FEM), are often employed to model the complex interactions of the antenna structure with electromagnetic waves, ensuring optimal design for applications like Wi-Fi or radar systems.

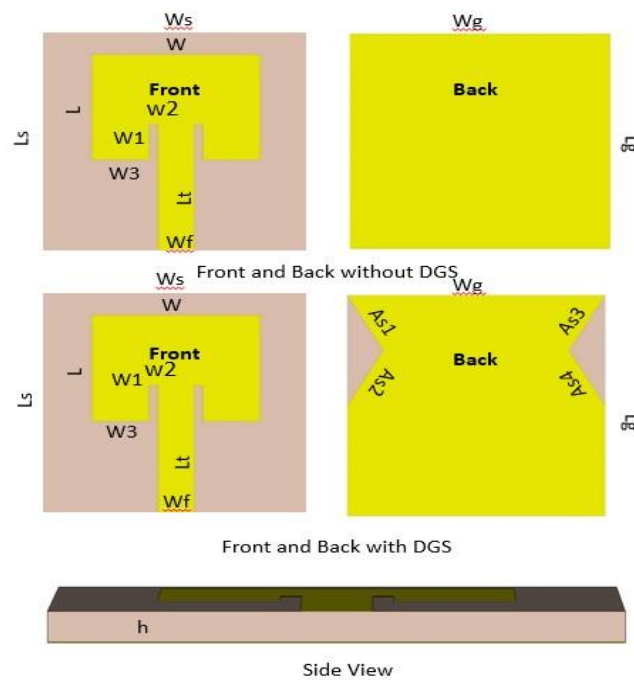


Fig 3.9 : Front, back with and without DGS

Table 3.1 Design parameters of the proposed antenna

$W_s, W_g$	25.00
$L_s, L_g$	25.00
$W$	15.75
$L$	11.88
$W_f$	3.14
$L_t$	14.56
$h$	1.60
$As_1, As_2, As_3, As_4$	7.16

W1	5.38
W2	0.93
W3	5.38

### 3.4.2 Applying DGS for performance improvement

The integration of a Defected Ground Structure (DGS) can significantly enhance the performance of an antenna operating at 5.8 GHz. DGS introduces deliberate alterations to the ground plane, such as slots or etched patterns, which disrupt the surface current distribution. This modification effectively controls the propagation of electromagnetic waves, leading to improved antenna characteristics. Specifically, DGS can enhance impedance bandwidth by reducing the quality factor (Q-factor) of the antenna, enabling broader frequency coverage around the desired operating frequency of 5.8 GHz. Additionally, it improves radiation efficiency by minimizing unwanted surface wave effects and suppressing spurious radiation, thereby increasing overall gain. The structure also contributes to better return loss by refining impedance matching. Moreover, DGS introduces a band-rejection or filtering capability, reducing interference from adjacent frequency bands. This results in a more efficient and focused antenna performance, making it highly suitable for applications like Wi-Fi, industrial automation, and wireless communication in the 5.8 GHz band. In this research we have applied two triangular slots at the back of the antenna to boost the performance of the proposed antenna.

### 3.4.3 Working Principle

Introducing slots into the ground plane effectively disrupts the original current distribution designed for single-band operation. These slots create intentional interruptions in the current path, compelling the currents to flow around them. This altered current flow modifies the electromagnetic field distribution, enhancing the antenna's performance. By carefully designing the shapes, sizes, and positions of the slots, the antenna's operational characteristics can be significantly improved. These modifications can lead to an increase in impedance bandwidth, better return loss, and higher radiation efficiency by suppressing surface wave propagation and unwanted resonances. The customized slots enable a new current distribution that supports multi-band or wideband performance while minimizing interference from adjacent bands. This approach allows greater control over the antenna's behavior, making it more versatile and suitable for modern communication systems, such as those operating in the 5.8 GHz frequency band. Proper slot design is critical to achieving optimal results.

The width of the patch is determined by the equation below,

$$W = \frac{c}{2f_r} \times \sqrt{\left(\frac{2}{\epsilon_r+1}\right)}$$

Where,

$c$  = Speed of light

$f_r$  = Resonant frequency

$\epsilon_r$  = Dielectric constant of the substrate

The length of the patch can be calculated by the equation below,

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L$$

Where,

$\epsilon_{reff}$  = Effective dielectric constant, that can be calculated as:

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + \frac{12h}{W}\right]^{-\frac{1}{2}}$$

$\Delta L$  = Length extension due to fringing field, that can be calculated as:

$$\Delta L = 0.412h \times \frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

$h$  is the thickness of the substrate.

### 3.5 Summary

This chapter 3 provides an overview of various antenna types, analyzing their strengths and weaknesses. We selected the rectangular patch antenna for our 5.8 GHz system due to its compactness, ease of integration, and suitability for high-frequency applications. While patch antennas offer advantages like compact size and ease of fabrication, they have a narrow bandwidth and lower gain compared to other types. Key parameters for antenna simulations include VSWR, radiation pattern, S-parameters, efficiency, and

field results. These parameters are essential for evaluating antenna performance in terms of impedance matching, radiation characteristics, and power efficiency. For material selection, dielectric substrates such as FR4, RT/Duroid, and PTFE are used, each offering different performance characteristics. The design and simulation are conducted using software like CST Microwave Studio. The design procedure involves selecting the antenna type, simulating its performance, optimizing its dimensions, and

validating the design through comparison with theoretical models. Equations like the resonant frequency formula and bandwidth equation guide the design process.

However, limitations such as bandwidth constraints, substrate material losses, and fabrication tolerances may affect performance. Despite these, the rectangular patch antenna is a reliable choice for 5.8 GHz applications.

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 Introduction

This chapter presents the results and performance analysis of the proposed microstrip patch antenna design. plane (without DGS) and another with a Defected Ground Structure (DGS). The performance metrics such as resonance frequency, return loss, bandwidth, gain, Voltage Standing Wave Ratio (VSWR), and radiation efficiency are analyzed and compared to evaluate the impact of DGS on the antenna's performance. The antenna has been simulated for two configurations: one with a conventional ground

The simulation results demonstrate the influence of DGS on key antenna parameters. By modifying the ground structure, the antenna exhibits improvements in bandwidth and gain while maintaining excellent impedance matching and VSWR. These results validate the potential of DGS in enhancing the performance of microstrip patch antennas for modern wireless communication systems.

The simulations were conducted for two configurations:

1. Without Defected Ground Structure (DGS)
2. With Defected Ground Structure (DGS)

### 4.2 Antenna Simulation & Result Analysis

#### 4.2.1 S-Parameter (Return Loss) Analysis

The return loss, represented by  $S_{11}S_{11}$ , indicates the power reflected back to the source due to impedance mismatch. Lower values of return loss correspond to better impedance matching.

- **Without DGS:** The return loss is measured as **-34.55 dB**, which indicates excellent impedance matching at the resonance frequency of 5.8 GHz. This low value suggests that minimal power is lost due to reflection.
- **With DGS:** The return loss slightly increases to **-31.64 dB**. While slightly higher, it is still well below the threshold of -10 dB, signifying good impedance matching and reliable operation.

The inclusion of DGS has minimal impact on return loss, ensuring that the antenna remains efficient in reflecting less power back to the source.

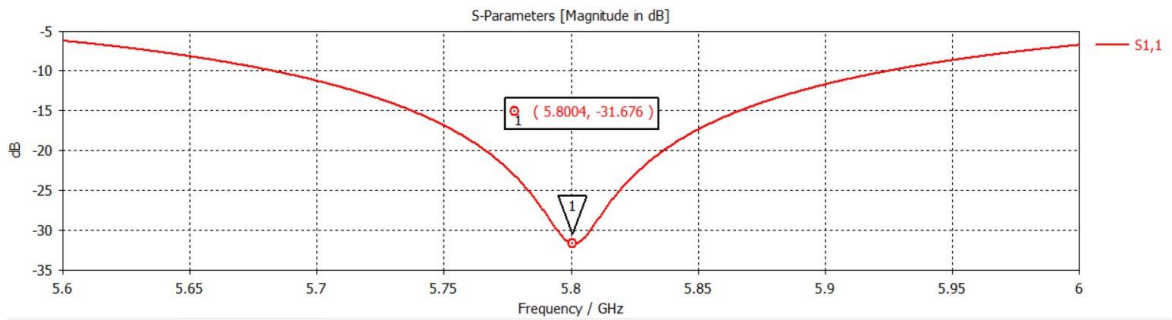


Fig 4.1: Return Loss with DGS

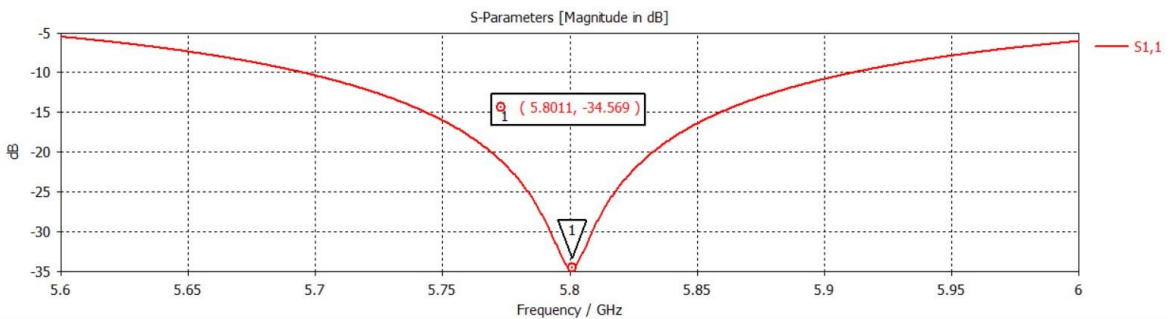


Fig4.2 : Return Loss without DGS

#### 4.2.2 Bandwidth Analysis

Bandwidth refers to the range of frequencies over which the antenna performs effectively. A broader bandwidth enhances the antenna's capability to handle varying frequency ranges.

- **Without DGS:** The bandwidth is measured as **215.1 MHz**.
- **With DGS:** The bandwidth improves to **240.9 MHz**, representing an increase of approximately **25.8 MHz (12%)**.

The DGS improves the bandwidth, allowing the antenna to operate over a wider frequency range. This makes the design more suitable for applications requiring robust and flexible frequency response.

#### 4.2.3 Voltage Standing Wave Ratio (VSWR) Analysis

VSWR is a measure of the power transmitted through the antenna compared to the power reflected back. A VSWR close to 1 indicates excellent impedance matching.

- **Without DGS:** The VSWR is **1.03**, which is almost ideal.
- **With DGS:** The VSWR is slightly higher at **1.05**, but still well below the acceptable threshold of 2.

The DGS has a negligible impact on the VSWR, ensuring reliable power transmission across both configurations.

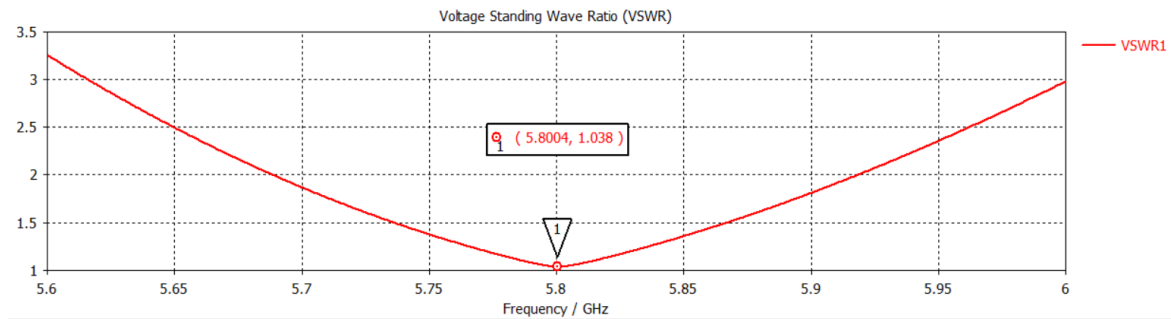


Fig 4.3 : VSWR without DGS

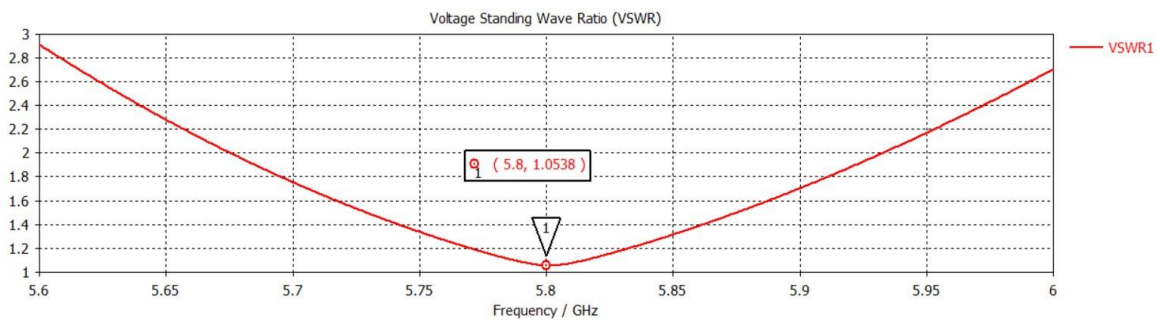


Fig 4.4 : VSWR with DGS

#### 4.2.4 Gain Analysis

Gain quantifies the antenna's ability to radiate power in a specific direction.

- **Without DGS:** The antenna achieves a gain of 1.98 dBi without incorporating a Defected Ground Structure (DGS). This value reflects the antenna's ability to radiate power in the desired direction relative to an isotropic radiator. While adequate, further enhancements in gain and performance can be achieved by integrating DGS into the design.
- **With DGS:** The gain improves significantly to **2.51 dBi**.

The increase in gain by **0.53 dBi (26.8%)** highlights the effectiveness of DGS in enhancing the directivity and radiation performance of the antenna.

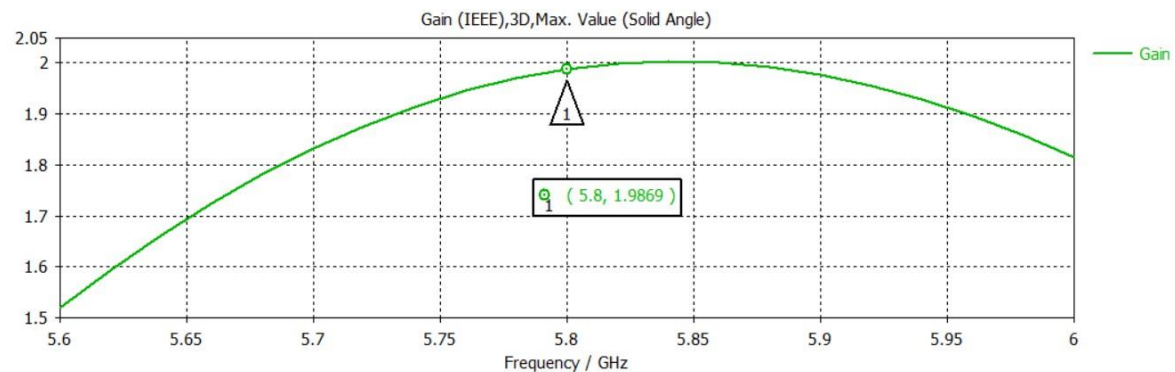


Fig 4.5 : Gain without DGS

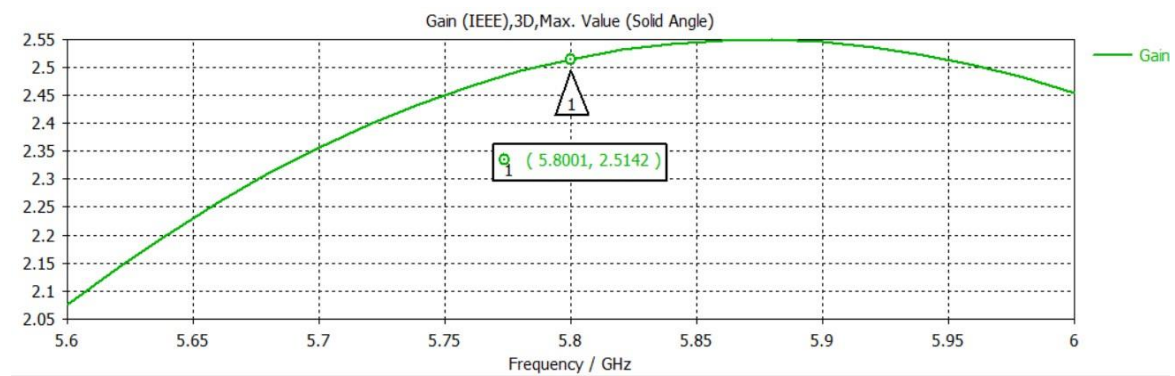


Fig 4.6: Gain without DGS

#### 4.2.5 2D and 3D Radiation pattern analysis

A 3D radiation pattern is a three-dimensional graphical representation of the radiation characteristics of an antenna. It illustrates how the antenna radiates or receives electromagnetic energy in all directions in space. The 3D radiation pattern is a crucial tool for understanding the performance of an antenna, as it provides a complete view of the directional strength of the radiation. A 2D radiation pattern is a graphical representation of an antenna's radiation properties in a specific plane, such as the azimuthal (horizontal) plane or the elevation (vertical) plane. It provides a two-dimensional view of how the antenna radiates or receives electromagnetic energy in a particular direction.

The proposed antenna achieves an almost omnidirectional radiation pattern, making it suitable for applications requiring uniform coverage. Figures 3 and 4 illustrate the 3D radiation patterns of the antenna with and without the Defected Ground Structure (DGS), demonstrating the impact of DGS on the radiation characteristics. Additionally, Figures 5

and 6 present the corresponding 2D radiation patterns, providing detailed insights into the antenna's performance in specific planes. These visualizations validate the effectiveness of the DGS in enhancing the radiation pattern.

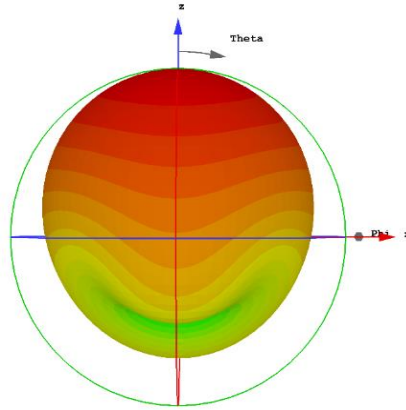


Fig 4.7 : 3D radiation pattern with DGS

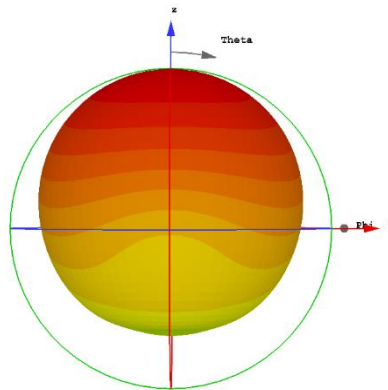


Fig 4.8 : 3D radiation pattern without DGS

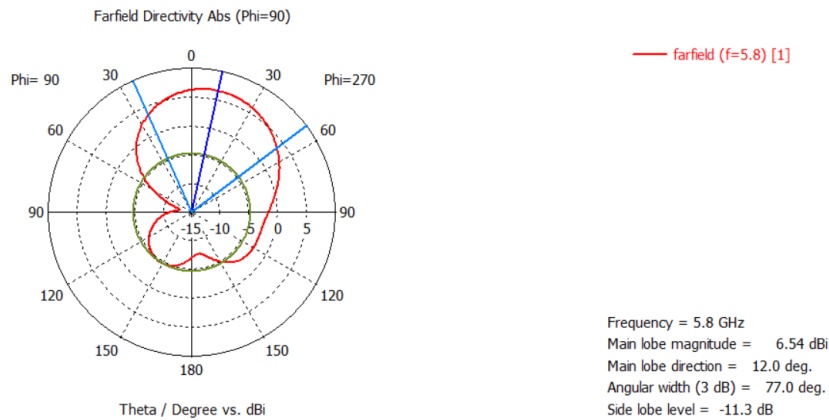


Fig 4.9 : 2D radiation pattern with DGS

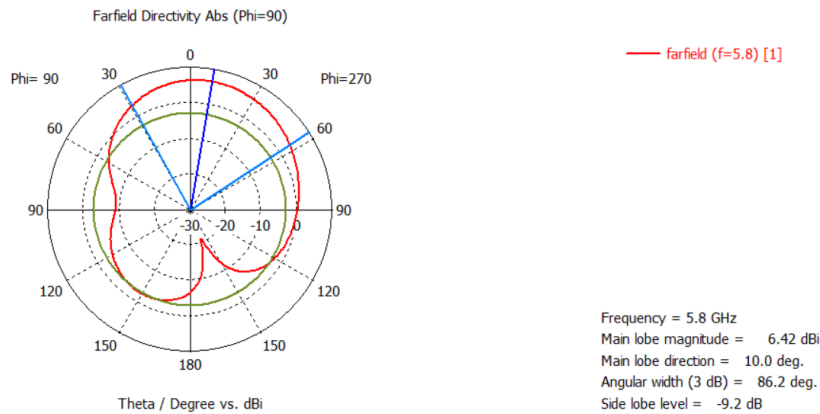


Fig 4.10: 2D radiation pattern without DGS

#### 4.2.6 Current Distribution

Figures 4.7 and 8 illustrate the current distribution of the proposed antenna with and without the incorporation of Defected Ground Structure (DGS). The current is predominantly concentrated towards the upper section of the antenna. By introducing slots into the ground plane, the original current distribution, optimized for single-band operation, is deliberately disrupted. These slots serve as interruptions in the current path, compelling the current to flow around them and altering the electromagnetic field distribution. The specific shapes, sizes, and positions of the slots play a critical role in determining the new current distribution, which directly impacts the antenna's overall performance. Observations reveal that with the addition of DGS, the current density is notably increased. This enhanced current concentration improves impedance matching and radiation efficiency, leading to better antenna performance. The use of DGS clearly demonstrates its effectiveness in optimizing the current flow and enhancing the operational characteristics of the antenna.

#### 4.3 Comparison of the proposed antenna with and without DGS

The 4.1 table below summarizes the comparison of key performance parameters:

Parameter	Without DGS	With DGS
Resonance Frequency	5.8 GHz	5.8 GHz
Return Loss	-34.55 dB	-31.64 dB
Bandwidth	215.1 MHz	240.9 MHz
Gain	1.98 dBi	2.51 dBi
VSWR	1.03	1.05
figuration	Uniform ground	Triangular cuts (DGS)

#### 4.4 Discussion

The results obtained from the simulation of the microstrip patch antenna with and without DGS demonstrate significant performance improvements. The resonance frequency of 5.8 GHz remains unchanged, indicating that the DGS does not affect the antenna's operational frequency. The return loss slightly decreases from -34.55 dB to -31.64 dB, which is still within acceptable limits for efficient performance. The bandwidth sees a notable improvement, increasing from 215.1 MHz to 240.9 MHz, reflecting a broader operating range due to the DGS. Similarly, the antenna gain improves significantly, rising from 1.98 dB to 2.51 dB, enhancing the directivity and overall radiation performance. The VSWR values remain near unity, with only a minor change from 1.03 to 1.05, ensuring effective impedance matching and minimal power loss.

These enhancements can be attributed to the role of the DGS in modifying the current distribution and improving the electromagnetic characteristics of the antenna. The increase in bandwidth and gain makes the antenna more suitable for modern wireless applications requiring high performance, such as Wi-Fi and IoT. Overall, the addition of DGS results in a well-optimized design with superior radiation characteristics while maintaining simplicity and compactness.

# CHAPTER 5

## PROJECT MANAGEMENT

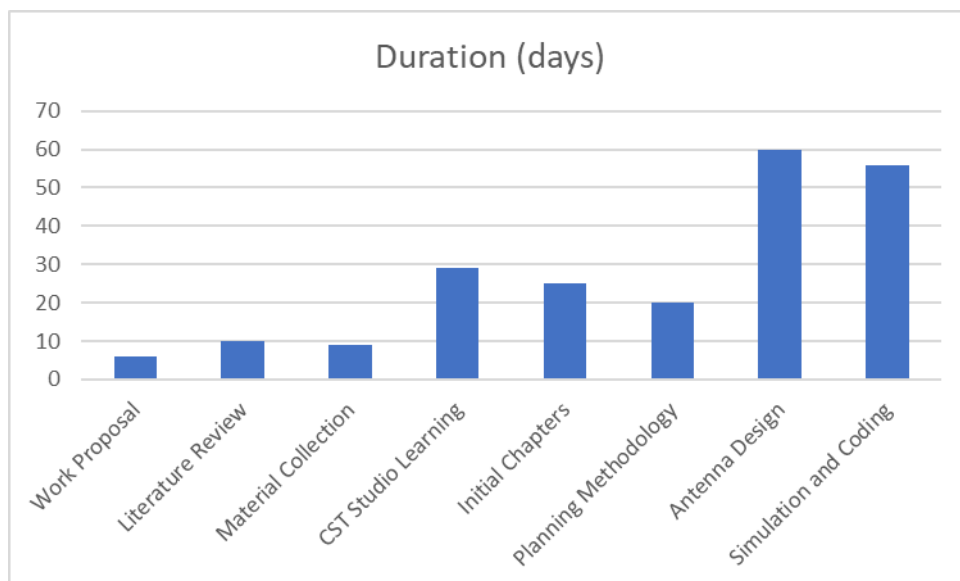
### 5.1 Task, Schedule and Milestones

The successful completion of our antenna design project required meticulous planning and adherence to a structured timeline. Key milestones were achieved as outlined below, demonstrating the effectiveness of our project strategy.

**Table 5.1: Task Completion Overview**

Task Title	Start Date	End Date	Duration (days)	% Completed
Work Proposal	05/05/2024	05/11/2024	6	100%
Literature Review	05/12/2024	05/22/2024	10	100%
Material Collection	05/23/2024	06/01/2024	9	100%
CST Studio Learning	06/02/2024	07/02/2024	29	100%
Initial Chapters	07/03/2024	07/28/2024	25	100%
Planning Methodology	07/29/2024	08/18/2024	20	100%
Antenna Design	08/19/2024	10/17/2024	60	100%

Although initial plans anticipated longer completion times, some tasks were finalized ahead of schedule due to optimized workflows. The Gantt chart below illustrates the timeline for each task.



**Fig 5.1 : Graph of project workday**

## 5.2 Resource Allocation and Cost Management

Effective resource management played a pivotal role in minimizing project expenses without compromising on quality. Leveraging the CST Studio Suite Learning Edition, a free resource for academic use, eliminated software licensing costs. Self-directed online training further enhanced our proficiency in using CST Studio, maximizing value while keeping expenses to a minimum.

Cost Breakdown:

- Software and Training: \$
  - Free student edition of CST Studio Suite.
  - Online tutorials and educational resources.
- Future Considerations: Advanced requirements may necessitate professional software editions, introducing licensing fees.
- Material Costs: Fabrication of physical antennas will incur additional expenses in future projects.

## 5.3 Lesson Learned

This project underscored the importance of strategic planning and resource optimization. Major accomplishments include:

- Completion of all milestones within the prescribed timeline, with some tasks finalized ahead of schedule.
- Cost-effective utilization of free educational software, demonstrating the value of freely available resources.
- Proficiency in technical tools acquired through self-learning, emphasizing the potential of online resources to offset training costs.

For future projects, advanced needs may necessitate professional-grade tools and additional budget considerations for material fabrication. Learning from this experience, maintaining adaptability and a cost-conscious approach will remain critical to successful project outcomes.

# CHAPTER 6

## IMPACT ASSESSMENT OF THE PROJECT

### 6.1 Economical, Societal and Global Impact

Microstrip patch antennas, such as the one we designed, are integral to the advancement and deployment of WLAN wireless communication. Their potential economic, societal, and global effects are as follows:

#### Economic Impact:

- **Cost Reduction:** Microstrip patch antennas offer several advantages over traditional antenna designs, such as compact size and lightweight construction. They can be fabricated using cost-effective materials and manufacturing processes, reducing overall production costs [15]. These factors contribute to significant savings in the production of WLAN base stations and user devices. The affordability of microstrip patch antennas makes them ideal for large-scale deployment. This cost reduction helps make wireless communication solutions more accessible and budget-friendly.
- **Market Growth:** The widespread adoption of WLAN technology will drive a significant increase in demand for microstrip patch antennas. This growth is expected to boost the antenna manufacturing industry, leading to industrial expansion. As production scales, it may generate new job opportunities, contributing to economic development. The rising demand emphasizes the importance of microstrip patch antennas in modern communication systems. Ultimately, this trend will support technological advancement and innovation.
- **Innovation and Investment:** The success of microstrip patch antennas in WLAN systems is likely to stimulate further research and development in antenna technology. This progress will foster innovations aimed at enhancing efficiency and performance. As a result, more advanced and high-performance antennas will be developed for future applications. Increased investment in antenna technology will accelerate technological advancements, driving the evolution of wireless communication systems. Ultimately, these innovations will expand the capabilities and applications of WLAN technologies.

### **Societal Impact:**

- **Enhanced Connectivity:** Microstrip patch antennas, with their compact size and easy integration, enable a denser network of WLAN base stations. This leads to enhanced coverage and improved connectivity, particularly in densely populated urban areas. The ability to deploy more base stations improves overall network performance. As a result, users experience better connectivity and more reliable wireless communication.
- **Improved Services:** The compact size and easy integration of these systems allow for the deployment of a more concentrated WLAN base station network. This enhances coverage and provides stronger connectivity, especially in densely populated urban areas. The increased network density improves overall communication quality, resulting in faster and more reliable wireless connections for users.
- **Bridging the Digital Divide:** Urban areas will greatly benefit from improved connectivity; however, strategically placing microstrip patch antennas can help close the digital divide in rural areas. This deployment will provide underserved communities with access to essential information, educational resources, and vital services. It can significantly enhance digital inclusion, ensuring equal opportunities for all regions.

### **Global Impact:**

- **Standardization and Interoperability:** Microstrip patch antennas that comply with established design standards ensure worldwide compatibility for WLAN networks. They facilitate smooth communication and reliable data exchange between devices and networks across different nations. This adherence to standards promotes uniform performance and global connectivity. Consequently, these antennas are essential for harmonizing wireless communication systems on a global scale.
- **Environmental Considerations:** The environmental impact of microstrip patch antennas is minimal, but their integration into WLAN technology can help foster sustainability. They facilitate smarter energy grids, more efficient resource utilization across various sectors, and enhanced remote monitoring of the environment. These innovations promote eco-friendly practices and increased efficiency. Ultimately, they contribute to building a more sustainable future.
- **Global Economic Growth:** The worldwide implementation of WLAN technology, supported by microstrip patch antennas, is projected to accelerate global economic growth. It will promote industrial development, generate employment opportunities, and improve the efficiency of trade and communication. This advancement is crucial for driving economic progress on a global scale.

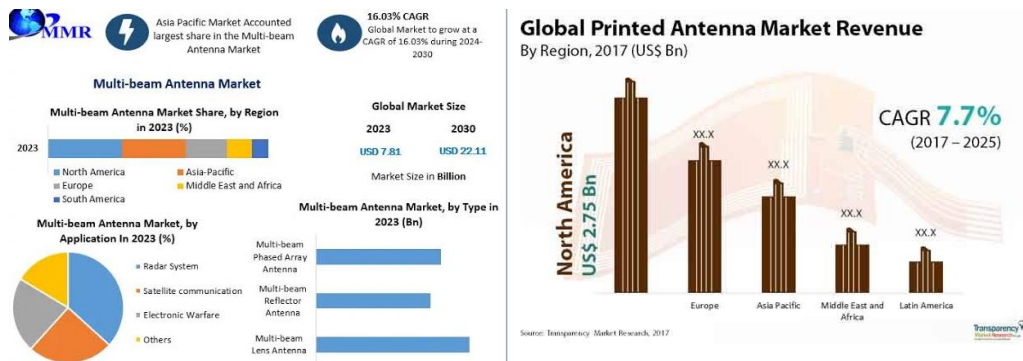


Fig 6.1 : Global Printed Antenna Market

## 6.2 Environmental and Ethical Issues

While microstrip patch antennas offer significant advantages for communication and technological advancement, it is essential to address various environmental and ethical challenges.

### Environmental Issues

- E-waste Generation:** The large-scale production of microstrip patch antennas, especially for WLAN base stations, may significantly increase electronic waste. To address this issue, the development of efficient disposal and recycling systems is crucial. Such measures can help minimize the environmental impact of antenna deployment. Responsible e-waste management is essential for sustainable technological growth.
- Potential Health Risks:** The health effects of extended exposure to electromagnetic radiation from telecommunications devices are still under discussion. More in-depth studies are essential to gain a clearer understanding of these risks and alleviate public concerns. Safe implementation of WLAN technology is vital. This approach will encourage responsible and secure use of wireless networks.

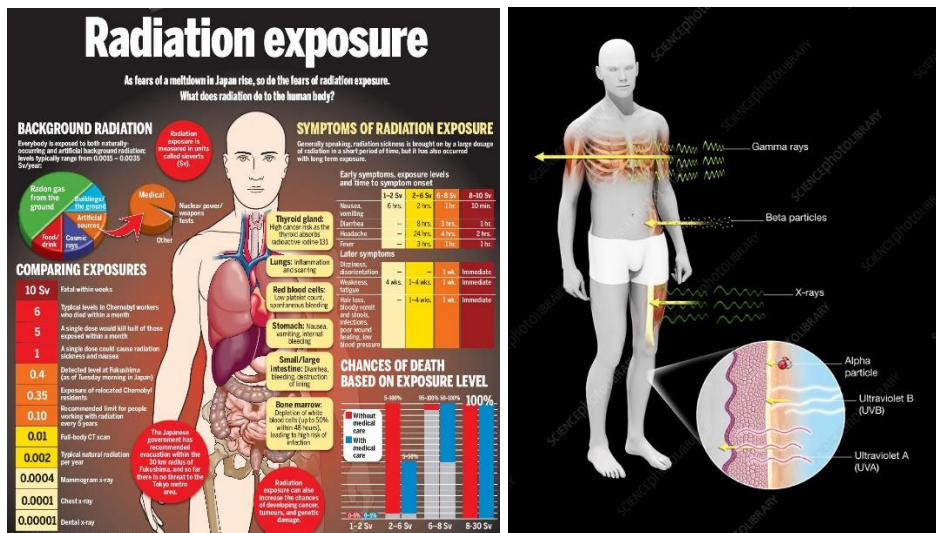


Fig 6.2 : Human tissue Injured by Unwanted Radiation

Radiation effects are more significant in specialized cells, which have limited ability to repair or regenerate after damage. The eye, being a highly specialized organ, is particularly at risk. Radiation can affect the lens and retina or harm the Meibomian glands, leading to a loss of the lipid layer in the tear film and increased evaporation. Damage to acinar cells in the lacrimal glands may also contribute to ocular dryness. This study found that patients with conjunctival or orbital lymphoma who received an average radiation dose of 37.4 Gy had markedly different Schirmer test, Break-up Time test, and OSDI questionnaire results compared to 60 healthy individuals[16].

### Ethical Issues

- **Privacy Concerns:** The increased data transmission and connectivity through WLAN technology bring important privacy challenges. Strong security measures and privacy policies are essential to protect personal data and prevent unauthorized access. Safeguarding user information is crucial to mitigate risks. Ensuring privacy will foster trust and encourage safe adoption of the technology.
- **Responsible Manufacturing:** Responsible manufacturing of microstrip patch antennas involves sourcing materials ethically and sustainably. This includes using environmentally friendly practices, supporting fair labor conditions, and reducing ecological impact. Ensuring compliance with ethical standards promotes social responsibility. Ultimately, it helps balance technological advancement with environmental and human welfare.

# CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

### 7.1 Conclusions

The design of our single-band microstrip patch antenna for WLAN communication at 5.8 GHz has demonstrated remarkable results through simulations. Careful analysis and optimization have led to significant enhancements in performance, particularly for single-band operation at this frequency. The **S-parameter analysis** revealed excellent return loss values of **-34.55 dB** without the use of a defected ground structure (DGS) and **-31.64 dB** with DGS, indicating strong impedance matching and efficient power transfer. These results align with our primary objective of reducing signal reflection and achieving reliable antenna operation.

The **bandwidth analysis** also yielded promising results, with bandwidths of **215.1 MHz** (without DGS) and **240.9 MHz** (with DGS). These values surpass the typical requirements for many wireless communication systems, enhancing the antenna's versatility and providing room for potential frequency expansions. Similarly, the **VSWR analysis** confirmed excellent impedance matching within the 5.8 GHz band, ensuring efficient signal transmission and improved radiation performance.

The antenna's ability to focus radiation in specific directions was confirmed through **directivity analysis**, which demonstrated improved communication range and reliability. **Gain analysis** further highlighted satisfactory levels for single-band operation, verifying the antenna's effectiveness in transmitting and receiving signals at 5.8 GHz. Additionally, the **radiation pattern analysis** revealed well-defined main lobes and minimal sidelobes, indicating effective energy concentration and reduced power loss in unwanted directions.

Overall, the consistent performance across key metrics reinforces the reliability and robustness of the proposed single-band microstrip patch antenna, making it a strong candidate for a wide range of wireless communication applications. Its efficiency and reliability are particularly advantageous for IoT environments, where dependable 5.8 GHz operation is critical.

In conclusion, the proposed antenna design proves to be an excellent solution for IoT and other modern wireless communication applications, offering a reliable and efficient single-band antenna for contemporary connectivity needs.

## 7.2 New Skills and Experiences Learned

While designing the Microstrip patch antenna for 5.8 GHz, I gained several key skills and insights:

- 1. Simulation Techniques:** Improved proficiency in HFSS or CST Microwave Studio to understand electromagnetic fields and optimize design parameters.
- 2. Impedance Matching and S-Parameter Analysis:** Gained practical experience in impedance matching and analysing S-parameters to ensure efficient power transfer and reduce signal reflections.
- 3. Optimization of Bandwidth and Efficiency:** Learned to adjust designs iteratively to enhance bandwidth and radiation efficiency for WLAN requirements.
- 4. Material Selection:** Developed a keen understanding of how substrate choices affect performance while balancing cost and fabrication constraints.
- 5. Radiation Patterns:** Analysed radiation patterns to improve directivity and reduce sidelobes through geometry modifications.
- 6. Real-World Application:** Gained practical experience applying antenna design in IoT and WLAN contexts, enhancing my understanding of their roles in wireless communications.
- 7. Problem-Solving Skills:** Overcame challenges related to resonance frequency and bandwidth, honing my troubleshooting abilities in antenna design.

These experiences have expanded my microstrip patch antenna knowledge and prepared me for future work in wireless communication.

## 7.3 Future Recommendations

Although the current microstrip patch antenna design shows strong performance in simulations, but there is potential for further optimization. Future work should target key areas for refining and enhancing the design.

- 1. Implement MIMO Configuration:** To reduce multipath fading, improve data throughput, and ensure signal stability.
- 2. Apply Metamaterials:** Using metamaterials in antenna design can enhance bandwidth, achieve miniaturization, and improve gain, resulting in a more optimized and efficient antenna.

**3. Verification and Optimization:** Creating a prototype of the designed antenna is essential to connect simulation results with practical performance. Real-world testing of its S-parameters, radiation patterns, and gain in an anechoic chamber provides critical validation data. Comparing these measurements to the simulation results helps identify any deviations. These insights can then be used to fine-tune the simulation model, enhancing its accuracy for future designs.

By implementing these recommendations, future microstrip patch antenna designs can achieve enhanced performance, greater functionality, and improved environmental sustainability.

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## APPENDIX A

### COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

**Article I. Fulfillment of Program Outcomes (PO), Knowledge Profile (K), Range of Complex Engineering Problem Solving (P), and Range of Complex Engineering Activities (A)**

Attribute	Followed (Yes/No)	Explanation on How It Is Followed
Program Outcomes (PO)		
PO1: Apply knowledge of mathematics, natural science, engineering fundamentals, and specialization.	Yes	Applied electromagnetic theory, mathematics, and engineering principles in antenna design and performance optimization.
PO2: Identify, formulate, and analyze complex engineering problems.	Yes	Identified challenges in antenna gain, bandwidth, and impedance matching; analyzed solutions using simulation tools like CST Studio.
PO3: Design solutions for complex engineering problems.	Yes	Designed a microstrip patch antenna with DGS, ensuring improved bandwidth and gain while meeting WLAN communication requirements.
PO4: Conduct investigations of complex problems using research methods.	Yes	Conducted simulations to investigate the effect of DGS on antenna performance; validated results with comparative analysis.
PO5: Use modern engineering tools with an understanding of limitations.	Yes	Used CST Studio Suite for modeling and analysis, understanding its constraints in practical applications.
PO6: Apply reasoning informed by societal, health, and safety contexts.	No	We didn't maintain this problem solving.

PO7: Understand and evaluate sustainability and societal impact.	Yes	Designed efficient, cost-effective antennas with minimal environmental impact, addressing societal needs for reliable IoT and WLAN communication.
PO8: Apply ethical principles and commit to professional ethics.	Yes	Followed IEEE and FCC standards, ensuring ethical design practices.
PO9: Function effectively in teams.	Yes	Worked collaboratively as a team to achieve project goals, including simulation, analysis, and documentation.
PO10: Communicate effectively with society and engineering community.	No	We didn't maintain this problem solving.
PO11: Demonstrate knowledge of engineering management and economic decision-making.	Yes	Managed project resources, timelines, and cost-effectiveness as shown in the Gantt chart and resource allocation sections.
PO12: Engage in life-long learning.	Yes	Gained new skills in advanced simulation tools and explored novel antenna optimization techniques.
Knowledge Profile (K)		
K1: Understanding of natural sciences.	Yes	Applied electromagnetic wave theory and principles in antenna performance improvement.
K2: Conceptually based mathematics for analysis and modeling.	Yes	Used mathematical models to calculate patch dimensions and optimize resonance frequency.
K3: Systematic theory-based formulation of engineering fundamentals.	Yes	Developed antenna designs grounded in theoretical knowledge of electromagnetic fields and microstrip patch principles.
K4: Specialist knowledge for accepted practices in the engineering discipline.	Yes	Used advanced techniques like DGS integration to improve antenna performance, a recognized practice in wireless

		communication engineering.
K5: Knowledge supporting engineering design.	Yes	Designed antennas to meet 5.8 GHz WLAN requirements, considering bandwidth, gain, and impedance matching.
K6: Knowledge of engineering practice (technology).	Yes	Utilized advanced simulation tools (CST Studio) and fabrication methods for prototyping the antenna.
K7: Comprehension of societal and environmental impacts.	Yes	Addressed environmental sustainability and societal needs through efficient and scalable antenna design.
K8: Engagement with selected knowledge in the research literature.	Yes	Reviewed and incorporated relevant research on DGS-based antenna optimization.
Range of Complex Engineering Problem Solving (P)		
P1: Requires in-depth engineering knowledge (K3-K8).	Yes	Solved problems using advanced knowledge of electromagnetic fields, DGS, and antenna theory.
P2: Involves wide-ranging or conflicting requirements.	No	We didn't maintain this problem solving.
P3: Requires abstract thinking and originality.	Yes	Developed innovative DGS patterns and analyzed their effects on performance through simulations.
P4: Involves infrequently encountered issues.	Yes	Addressed unique challenges in optimizing DGS for high-frequency antennas.
P5: Outside standard practices and codes.	No	We didn't maintain this problem solving.
P6: Involves diverse stakeholder needs.	No	We didn't maintain this problem solving.
P7: Includes many sub-problems or components.	No	We didn't maintain this problem solving.
Range of Complex Engineering Activities (A)		

A1: Involves diverse resources.	Yes	Utilized simulation tools, materials, and collaborative team efforts.
A2: Resolves significant problems from interactions of issues.	No	We didn't maintain this problem solving.
A3: Creative use of engineering principles.	No	We didn't maintain this problem solving.
A4: Significant societal and environmental consequences.	No	We didn't maintain this problem solving.
A5: Extends beyond previous experiences.	Yes	Explored new DGS configurations and optimized current distributions for 5.8 GHz operation.

# APPENDIX B

## TURNITIN REPORT

203-33-1326

### ORIGINALITY REPORT

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