



Faculty of Engineering

**Analysis of modified back-line inset feed 1×4 array microstrip antenna
for 5.8 GHz frequency band**

Mohammad Fazlul Hasan

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Analysis of modified Back-Line Inset Feed 1×4 Array microstrip Antenna for 5.8 GHz Frequency Band

Mohammad Fazlul Hasan

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

..........

Signature

Name: Mohammad Fazlul Hasan

Matric No: 20020330

Faculty of Engineering

Universiti Malaysia Sarawak

Date : 21-10-2025

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ABSTRACT

This thesis presented the design and optimization of a compact 1×4 microstrip patch array antenna operating at 5.8 GHz using a modified backline feeding technique. Conventional arrays often suffer from mutual coupling caused by surface currents on the feedline, bulky isolation methods that lower gain, narrow bandwidth, challenging impedance matching, and feedline radiation that degrades polarization purity. The study had three objectives: (i) to design and optimize the array for good impedance matching ($S_{11} \leq -10$ dB) and stable resonance through parameter sweep analysis, (ii) to evaluate and enhance bandwidth, gain, and directivity, and (iii) to investigate polarization purity and side lobe behaviour, targeting cross-polarization < -30 dB and acceptable side lobe levels while assessing the effects of coupling and substrate losses. It was hypothesized that the optimized array would achieve stable broadside radiation, higher gain and directivity than a standard-fed array, reduced mutual coupling through the backline layout, and practical impedance matching across the band. The final design achieved resonance at 5.8 GHz with a measured return loss of -21.947 dB, a VSWR of 1.173, and a -10 dB bandwidth of approximately 5%, confirming excellent matching performance. Experimental results further demonstrated a directivity of 10.29 dBi, improved gain relative to a single patch, and balanced excitation leading to stable radiation patterns. Side lobes were kept within acceptable limits and cross-polarization remained below -30 dB, validating the design approach. Overall, the proposed array successfully met its objectives, delivering a compact, efficient, and polarization-pure solution for WLAN/ISM band applications, with measured performance closely matching theoretical expectations and published benchmarks.

Keywords: Microstrip 1x4 Array antenna, 5.8GHz frequency band, Back line feeding, CST studio, Impedance Marching, Mutual coupling,

Analisis Dan Penilaian Prestasi Antena Mikrostrip Susunan 1×4 Dengan Suapan Lepak Garis Belakang Yang Diubah Suai Untuk Jalur Frekuensi 5.8 Ghz

ABSTRAK

Tesis ini membentangkan reka bentuk dan pengoptimuman antena susunan tampalan mikrostrip 1×4 pada 5.8 GHz menggunakan teknik suapan belakang yang diubah suai. Antena susunan konvensional sering menghadapi masalah seperti gandingan bersama akibat arus permukaan pada saluran suapan, lebar jalur sempit, pencocokan impedans yang sukar, dan radiasi saluran suapan yang menjejaskan ketulenan polarisasi. Objektif kajian ini adalah untuk (i) mereka bentuk dan mengoptimumkan susunan bagi mencapai pencocokan impedans yang baik ($S_{11} \leq -10$ dB) serta frekuensi resonan yang stabil, (ii) menilai dan meningkatkan lebar jalur, keuntungan dan keterarahan, dan (iii) menyiasat ketulenan polarisasi serta tingkah laku lob sisi, dengan sasaran polarisasi silang < -30 dB dan tahap lob sisi yang boleh diterima. Susunan yang dioptimumkan dijangka memberikan radiasi sisi lebar yang stabil, keuntungan dan keterarahan yang lebih tinggi, gandingan bersama yang berkurang serta pencocokan impedans yang baik merentasi jalur operasi. Reka bentuk akhir mencapai resonan pada 5.8 GHz dengan kerugian pantulan -21.947 dB, VSWR 1.173, dan lebar jalur -10 dB sekitar 5%. Keputusan eksperimen menunjukkan keterarahan 10.29 dBi, peningkatan keuntungan berbanding tampalan tunggal, corak radiasi stabil, lob sisi rendah, dan polarisasi silang di bawah -30 dB. Secara keseluruhan, susunan yang dicadangkan memenuhi objektif kajian dan menawarkan reka bentuk padat, cekap serta sesuai untuk aplikasi jalur WLAN dengan prestasi yang hampir sepadan dengan jangkaan teori dan literatur.

Kata kunci: *Microstrip 1x4 array, 5.8GHz, Backline feed, CST, pencocokan Impedans, WLAN*

TABLE OF CONTENTS

	Page
DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
<i>ABSTRAK</i>	iv
TABLE OF CONTENTS	v
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF ABBREVIATIONS	xiii
CHAPTER 1: INTRODUCTION	1
1.0 Study Background	1
1.1 Problem Statement	3
1.2 Objectives	5
1.3 Project Scope	5
1.4 Chapter Summary of thesis	7
CHAPTER 2: LITERATURE REVIEW	9
2.0 Overview	9
2.1 Wireless Communication Scenario and Real Application	9

2.2	Wireless Connectivity in Sarawak	10
2.2.1	Wireless Applications	11
2.2.2	Wireless Communication on Residential Welfare	12
2.2.3	Wireless Connectivity for Transportation	13
2.2.4	Wireless Network Communication Based Digital/Smart Agriculture in Rural Areas	14
2.2.5	Forest Internet of Things (IoT) Using Wireless Network Communication	15
2.2.6	Wireless Communication Technologies for Advanced Underground Mining Operations	16
2.2.7	Wireless Network Communication for Fishing and Hunting	17
2.3	Microstrip Antenna Important parameters and Configurations	18
2.3.1	Different Types of Feeding Techniques	19
2.3.2	Frequency	19
2.3.3	Fringing Effect	19
2.3.4	Radiation Pattern	20
2.3.5	Return Loss	21
2.3.6	Directivity	22
2.3.7	Gain of an Antenna	23
2.3.8	Bandwidth	23
2.3.9	Antenna Efficiency	24

2.3.10	Polarization	24
2.3.11	Substrate	27
2.4	Microstrip Patch Array Antenna	28
2.4.1	Different Shapes of Microstrip Antennas	28
2.4.2	Improvement of Microstrip array Antennas at 5.8 GHz	29
2.4.3	Inset Feed Single Array Directional Antenna	30
2.4.4	Coaxial Feed Array Directional Antenna	31
2.4.5	Aperture Coupled Feed Array Antenna	31
2.4.6	Proximity Coupled Feed Array Antenna	32
2.4.7	Characteristic of Different Feed Techniques	33
2.4.8	Performance of Microstrip Antenna through Inset Feed Method	34
2.4.9	Microstrip array antenna for 5G mobile communication at 5.8 GHz	35
2.4.10	Directional Microstrip array Antenna at UHF-Band for Passive Radar Application	36
2.4.11	2x2 Directional Microstrip Array Antenna	36
2.4.12	Previous Related Works and SOTA Table	39
2.5	Research Gap	43
2.6	Chapter Summery	45
CHAPTER 3: METHODOLOGY		46
3.0	Overview	46

3.1	Flow Chart	47
3.2	Design of 1x4 Microstrip patch Array Using CST Microwave Studio:	48
3.3	Geometry of microstrip array antenna using back-line feed technique	52
3.4	Design of Backline feed	54
3.5	Fabrication	61
3.6	Methodology for Experiment or testing final Antenna	63
3.7	Chapter Summary	64
CHAPTER 4: RESULT AND DISCUSSION		66
4.0	Overview	66
4.1	Simulation Results	67
4.1.1	Parameter Sweeps Evaluation	67
4.1.2	Return Loss	69
4.1.3	Bandwidth of Resonance Frequencies	70
4.2	Radiation Pattern	72
4.3	Fabricated prototype measurement	82
4.4	Comparison Analysis of the Proposed Antenna Results with Theories and Literatures	84
4.5	Analysis of Simulated and Experienced Result	88
4.7	Chapter Summary	92
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS		94
5.0	Conclusion	94

5.1	Advantages of the Backline Feed Technique	96
5.2	Recommendations and Future work	98
	REFERENCES	100
	APPENDICES	113

LIST OF TABLES

	Page
Table 2.1 Characteristic of Different Feeding Techniques	33
Table 2.2 Antenna Designs and Performance Metrics from Recent Studies	42
Table 2.3 Identified Challenges of Current Method	44
Table 3.1 List of Proposed Microstrip Antenna Specification	51
Table 3.2 List of Backline Feed Specification	57
Table 4.1 Observation of the width of antenna patch at 5.8GHz	67
Table 4.2 Characteristic of the Resonant Frequency and Return Loss $S_{1,1}$ as a Function of Changing Antenna Dimensions from Figure 26	69
Table 4.3 Comparison of proposed technique results between theory and literature	88
Table 5.1 Overview of Back Line Feed Technique Benefits	98

LIST OF FIGURES

	Page
Figure 2.1 (a) Urban and Rural Territory; (b) Sarawak Linking Urban, Rural and Nation	11
Figure 2.2 Demonstration of applications and opportunities for future wireless Communications	12
Figure 2.3 System architecture of ITS in Rural Areas by using Wireless Network	13
Figure 2.4 Broadband on digital farming by using IoT	14
Figure 2.5 Realization of Multiple Lora-Support Solar Micro-Weather Stations with Repeat Stations, And Communication Technology	15
Figure 2.6 Illustration of Forest Alert Monitoring System (SAFe) System Architecture	16
Figure 2.7 Data Rate Vs. (Aboveground) Radio Communication Technologies at Mining Sector	17
Figure 2.8 Feeding Method of Microstrip Array Antenna	19
Figure 2.9 (a) 3D Format and (b) Polar Format of Radiation Pattern	21
Figure 2.10 Return Loss of Microstrip Antenna	22
Figure 2.11 Different types of polarization (a) Theta phase and (b) Phi phase	26
Figure 2.12 Configuration of different shapes of array patch antenna	29
Figure 2.13 Inset Feeding Method of Microstrip Array Antenna	30
Figure 2.14 Coaxial Feed method of microstrip array antenna	31
Figure 2.15 Aperture coupled feed method of microstrip array antenna	32
Figure 2.16 Proximity coupled feed method of microstrip array antenna	33
Figure 3.1 Flowchart	47
Figure 3.2 Minimum and Maximum Frequency Selection in CST Software	48
Figure 3.3 Brick Window	49
Figure 3.4 Microstrip Antenna 5.8 GHz with 1x4 Array (Front View)	54

Figure 3.7	Feeding Technique with Backward Line	57
Figure 3.8	Proposed Design for 5.8GHz Microstrip antenna by using BLF	61
Figure 3.9	Fabrication of final prototype in lab	63
Figure 3.10	Testing the proposed antenna and experiment the result in Lab	64
Figure 4.1	Reflection Coefficient for Different Values of Width	67
Figure 4.2	Simulated S_{11} (dB) result of 5.8 GHz	70
Figure 4.3	High frequency and Lower frequency at 5.8 GHz	71
Figure 4.4	Directivity at 5.8GHz frequency	73
Figure 4.5	Realized gain (3D view) at 5.8GHz frequency	74
Figure 4.6	Polar Form of Realized Gain at 5.8 GHz Frequency	75
Figure 4.7	(a) 3D view of IEEE gain, (b) Polar plot of IEEE gain.	77
Figure 4.8	(a) E-plane Co-polarization, (b) E-plane cross-polarization	79
Figure 4.9	(a) H-plane Co-polarization (b) H-plane Cross polarization	80
Figure 4.10	Impedance Matching at 5.8 GHz Resonance Frequency	81
Figure 4.11	Surface Current at 5.8 GHz	82
Figure 4.12	Fabricated Arrays of Proposed Antenna (a) Substrate-1 Array (W x L), (b) Substrate-2 Back Line Feed (W x L), (c) Printed Antenna Array, (d) Final Prototype (Assembled)	85
Figure 4.13	S_{11} (dB) Return Loss of Proposed Antenna (Simulation and Experimental)	90
Figure 4.14	Imperfect fabrication prototype	91
Figure 4.15	Unwanted result due to faulty fabrication of the prototype	93

LIST OF ABBREVIATIONS

MSA	Microstrip Antenna
BLF	Back Line Feed
VSWR	Voltage Standing Wave Ratio
BW	Bandwidth
G	Gain
EM	Electromagnetic
IoT	Internet of Things
WLAN	Wireless Local Area Network
UHF	Ultra High Frequency
LHF	Low High Frequency
ISM	Industries, Scientific & Medical
E- field	Electric field
H-field	Magnetic field

CHAPTER 1

INTRODUCTION

1.0 Study Background

The interest in wireless communication systems has surged dramatically in recent years due to economic factors, and the market demand continues to grow. Antennas play a crucial role in these systems, making them one of the most significant design challenges in modern mobile communication. For both commercial and military purposes, there is a high demand for wideband, single/multiband, and low-profile antennas in today's wireless communication systems (Zakri et al., 2013). This demand has driven extensive research in various directions. Traditionally, antennas operate at a single or dual frequency bands, necessitating the use of single antennas for different applications. However, this approach presents space and placement challenges. To address these issues, the development of single band antennas has emerged, offering a solution that allows a single antenna to operate across single frequency bands. A key advantage of single band antennas is their straightforward design. A single-band antenna is generally described as a system designed to operate within one specific frequency band, focusing its performance on that band alone rather than covering multiple or separate frequency ranges. (Hussain et al., 2023).

In recent years, mobile phone technology has significantly reduced the weight and size of devices. As a result, antennas for mobile handheld devices must now be compact, lightweight, low-profile, and feature an omni-directional radiation pattern in the horizontal plane. However, challenges remain regarding antenna performance when interacting with the user's head and hand. User movement while using the mobile device can cause variations in gain, radiation pattern, and input impedance.

Antennas in handheld transceivers for personal communications are vital components that can significantly enhance or restrict system performance, particularly concerning bandwidth and efficiency. To design a handset with optimal performance, engineers must focus on the antenna systems of mobile transceivers. Wireless environments are highly unpredictable and challenging, yet mobile networks are expected to perform as reliably as wired networks, providing distortion-free connections. Service providers risk losing customers if they fail to meet these expectations (Saxena & Rajawat, 2020). Consequently, they must evaluate network performance and consider the impact of geographical and man-made obstacles before deployment. However, even simple wireless scenarios are complex to analyse accurately due to the numerous parameters involved. Users within the coverage area of a specific base station may encounter issues like weak signal strength or frequent call drops, even while stationary, due to factors such as shadowing attenuation, inadequate coverage from antenna height or power, or poor handoff performance (M. T. Ali, Aizat, et al., 2011; Rana et al., 2023). This thesis introduces a novel microstrip antenna featuring a modified backline feeding technique, which constitutes the primary innovation of this study. The antenna design was simulated using CST (Computer Simulation Technology), a widely used tool for electromagnetic analysis. To validate the simulation results, a physical prototype of the backline feed array antenna was fabricated and tested under controlled laboratory conditions, marking a significant milestone in this research. The evaluation of the microstrip antenna employing the modified backline feeding technique revealed substantial performance improvements of some parameters. The simulation results indicated enhanced characteristics such as gain, return loss, and directivity. These findings were further collaborated by the hardware prototype, which demonstrated the practical success of the proposed approach in real-world scenarios.

1.1 Problem Statement

In microstrip antennas, there is often some degree of interaction, or coupling, between different parts of the structure when mounted on the same substrate, whether used as a single element or in an array. This coupling primarily arises from three mechanisms: the flow of conducting currents along the metallic ground and feeding lines, the influence of radiated electromagnetic fields in the surrounding space, and the leakage of surface waves that travel through the substrate. Together, these effects can strongly impact the overall performance of the antenna, particularly in terms of efficiency and radiation characteristics. Mutual coupling in antenna arrays is often attributed to the radiation interaction between closely spaced elements, but research has shown that the feeding network itself plays a major role as well. According to Gu (2024), feed lines do not only serve as energy carriers to excite the antenna elements but also act as unintended coupling paths. Surface currents that flow along these lines can leak into adjacent elements, disturbing their excitation and altering the array's overall performance. Similarly, Zhang et al. (2023) explain that the electromagnetic fields generated around the feeding structure are not always confined to the intended patch. Instead, part of the energy radiates outward, where it interacts with nearby elements, creating additional coupling effects. This means that even with proper element spacing, the design of the feeding network must be carefully considered to minimize unwanted mutual coupling. It is crucial to note that a significant mismatch between the antenna and the feed line will result in a consistently high $S_{1,1}$ parameter, leading to undesirable outcomes such as increased return loss and reduced antenna gain (M. T. Ali, Alias, et al., 2011). Return loss and gain are primarily influenced and regulated by the feed line technique, which can generate harmonics that impact the antenna's bandwidth (Yassin et al., 2019). Traditional inset feed antennas, especially in microstrip designs, face several challenges. Common issues include distortion

in the radiation pattern, difficulties in achieving optimal impedance matching, limited bandwidth, radiation from the feedline itself, and potential for polarization purity, presence of side lobes in the radiation pattern, and sensitivity to variations in substrate properties (Chemkha & Belkacem, 2020). Microstrip array antennas often encounter challenges such as achieving lower- than-desired gain and directivity, and poor radiation efficiency. These issues arise from the configuration of the array, where closely spaced antenna elements and the choice of materials can impact overall performance. Additionally, poor radiation efficiency means that not all the input power is effectively converted into radiated electromagnetic waves. Factors such as the proximity of antenna elements within the array and the materials used can contribute to losses and inefficiencies in the radiation process.

One of the critical challenges faced by antennas is the loss of power along the feed line, as well as losses in the dielectric material and radiation (Abdulhussein et al., 2021). These losses collectively reduce the amount of power effectively delivered to the antenna, leading to decreased radiation purity. Feed line resistance losses occur when electrical energy is dissipated as heat along the transmission line that delivers power to the antenna. This Inefficiency can significantly impact the antenna's ability to transmit or receive signals effectively, especially over longer distances or at higher frequencies (Olan-Nunez et al., 2020).

Radiation losses occur when not all the electromagnetic energy generated by the antenna is radiated into free space. Factors such as the design of the antenna and the materials used can influence these losses, potentially reducing the antenna's overall effectiveness in communication or sensing applications.

1.2 Objectives

The problem and research gap can be achieved through the following set of objectives:

- i. To design and optimize a 1×4 microstrip patch array antenna at 5.8 GHz using backline feeding technique, ensuring good impedance matching (≤ -10 dB return loss) and stable resonance frequency through parameter sweep analysis.
- ii. To evaluate and enhance the antenna's performance characteristics such as bandwidth, gain, directivity, and to compared them against theoretical expectations and published literature values in the 5–6 GHz range.
- iii. To investigate polarization purity and side lobe behaviour of the proposed array, ensuring low cross-polarization levels (< -30 dB) and acceptable side lobe levels, while identifying trade-offs caused by mutual coupling and substrate losses.

1.3 Project Scope

The problem and research gap can be achieved through the following set of objectives:

- i. To Research and Background: Begin by studying existing microstrip antenna designs, particularly focusing on single-band antennas operating at 5.8 GHz.

Understand the principles behind the backline feed technique and how it affects the antenna's performance.

- ii. **Design Specifications:** Established the technical specifications for the antenna, including the desired gain, bandwidth, radiation pattern, and efficiency. The 1x4 array configuration implies you'll design a series of four microstrip elements working together to enhance the antenna's performance.
- iii. **Simulation and Modeling:** Use software CST to create a detailed model of the antenna. Simulate its behaviour to predict how it will perform at 5.8 GHz, making adjustments as needed to optimize the design.
- iv. **Prototype Development:** Once the design is finalized, proceed to fabricate a prototype. This involves selecting suitable materials, precise etching of the microstrip pattern, and ensuring the backline feed is correctly implemented.
- v. **Testing and Evaluation:** Test the prototype in a controlled environment to measure its performance against the specifications. Analyzed parameters such as return loss, VSWR (Voltage Standing Wave Ratio), and radiation pattern to ensure it meets the desired standards.

This scope outlines the key stages of the research, ensuring that each step is thoroughly planned and executed to achieve a functional and efficient microstrip antenna at the desired frequency.

Specific, testable expectations

- i. The array exhibits a clean main lobe with stable broadside radiation and controlled side lobes across the operating band.
- ii. Gain- is enhanced relative to a comparable array using a standard feed, consistent with more uniform element excitation.
- iii. Directivity- increases due to improved phase and amplitude balance along the feed path.
- iv. Mutual coupling- between adjacent elements is reduced by the modified backline layout, minimizing feed-induced interactions.
- v. Matching remains acceptable for practical operation ($S_{11} \leq -10$ dB and VSWR ≤ 2) over the intended bandwidth.

These statements are framed so they can be validated through full-wave EM simulation (and, if applicable, measurements), with comparisons to a baseline feeding network.

1.4 Chapter Summary of thesis

This thesis structured with five chapters:

Chapter one covered the introduction of this research, offered a brief overview of the microstrip antenna. It also outlines the objectives, problem statements, and the scope of the project.

Chapter two presented the literature review for this research. This chapter delves into theories related to modern wireless applications, single band microstrip antennas, microstrip antenna parameters, and various feeding systems. It also highlights previous research and identifies the research gaps relevant to this project.

Chapter three detailed the methodology used in this research, primarily focusing on the approach for developing the antenna's feeding system. It also covers the antenna design, project observations, and a detailed discussion of the flowchart.

Chapter four presented the results and analysis of the designed antenna, with a particular emphasis on comparing different feeding techniques.

Chapter five provided the overall conclusion of the project, summarizing the findings. It also addresses future recommendations, along with the advantages and disadvantages discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview:

The advancement of wireless communication systems has driven a growing demand for antennas that are not only compact but also capable of providing high efficiency, gain, and stable radiation performance. Among the many antenna types, micro strip patch arrays have received significant attention due to their lightweight structure, ease of fabrication, and suitability for integration into modern devices. Understanding the essential antenna parameters and design specifications is crucial in evaluating their effectiveness for real-world applications. In particular, the choice of feeding technique plays an important role in determining the overall performance of an array, as it directly influences factors such as impedance matching, bandwidth, and mutual coupling. Over the years, numerous studies have explored different designs and approaches, providing valuable insights but also revealing limitations that still need to be addressed. A careful review of these works highlights both the progress made and the research gaps that remain, ultimately motivating the need for further investigation into modified feeding methods for improved array antenna performance.

2.1 Wireless Communication Scenario and Real Application

The qualities of microstrip antennas make them particularly well-suited for rural wireless applications. Their small size and low weight mean they can be easily mounted on existing structures like rooftops or utility poles, which is ideal for places where building new infrastructure is challenging and costly. Additionally, their ability to perform well across different frequencies means they can adapt to various communication requirements in rural

settings. Existing research has shown that microstrip antennas can significantly improve wireless communication in rural areas. For example, a study by (Olan-Nunez et al., 2020; Sulaiman & Halamy, 2021). Demonstrated that these antennas could enhance signal coverage, leading to better connectivity and service quality. Another study by (Chien et al., 2003), found that deploying microstrip antenna arrays in rural networks is cost- effective, making it a feasible option for budget-constrained areas.

2.2 Wireless Connectivity in Sarawak

As defined in the 2012 delineation, which is based on the 2010 decennial census, rural areas include open countryside and settlements with fewer than 2500 residents. Figure 1 (a) illustrates that urban areas consist of larger population centers and the densely settled regions surrounding them (Sulaiman & Halamy, 2021). Urban areas are not strictly confined to municipal boundaries.

This research focuses on areas due to the prevalent issues with wireless connectivity. Rural Internet refers to the characteristics of Internet service in regions outside towns and cities, often called "the country" or "countryside," where people live in villages, hamlets, farms, and isolated houses. While traditional wireless networking technologies have effectively served urban areas in Sarawak, as shown in Figure 2.1 (b), they fall short of meeting the communication needs in rural environments (Chien et al., 2003). Over a billion people worldwide reside in rural communities where internet access is either poor or completely unavailable.

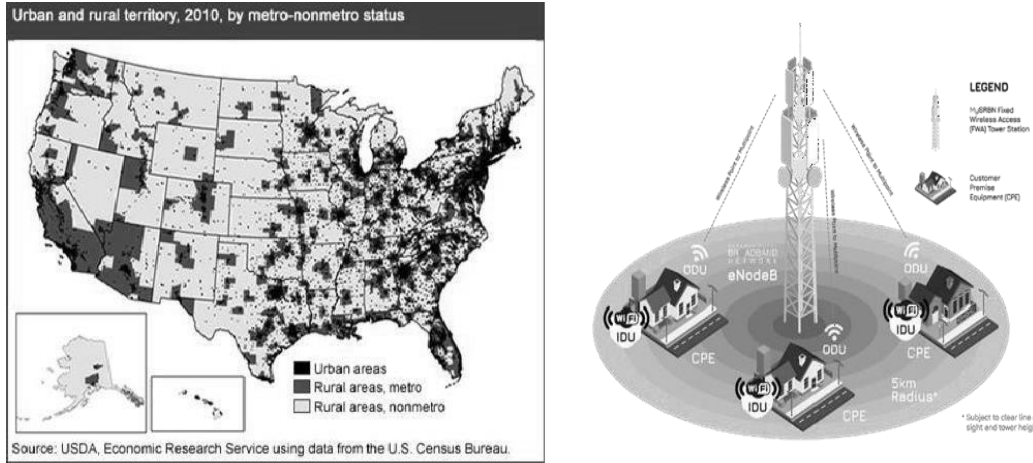


Figure 2.1: (a) Urban and Rural Territory (Sulaiman & Halamy, 2021) (b) Sarawak

Linking Urban, Rural and Nation (Chien et al., 2003)

2.2.1 Wireless Applications

Urban and rural area the connectivity is not same as users demand. This significantly restricts their access to essential digital services like telehealth and online education, as well as job opportunities that require telecommuting. From figure 2.2 multiple future applications are supporting to rural economics by using wireless connectivity (Yang et al., 2000).

According to a recent government report on the Benefits of wireless Coverage, improved digital connectivity in rural regions will boost productivity growth, provide safety benefits, and improve the quality of people's lives (Yang et al., 2000).

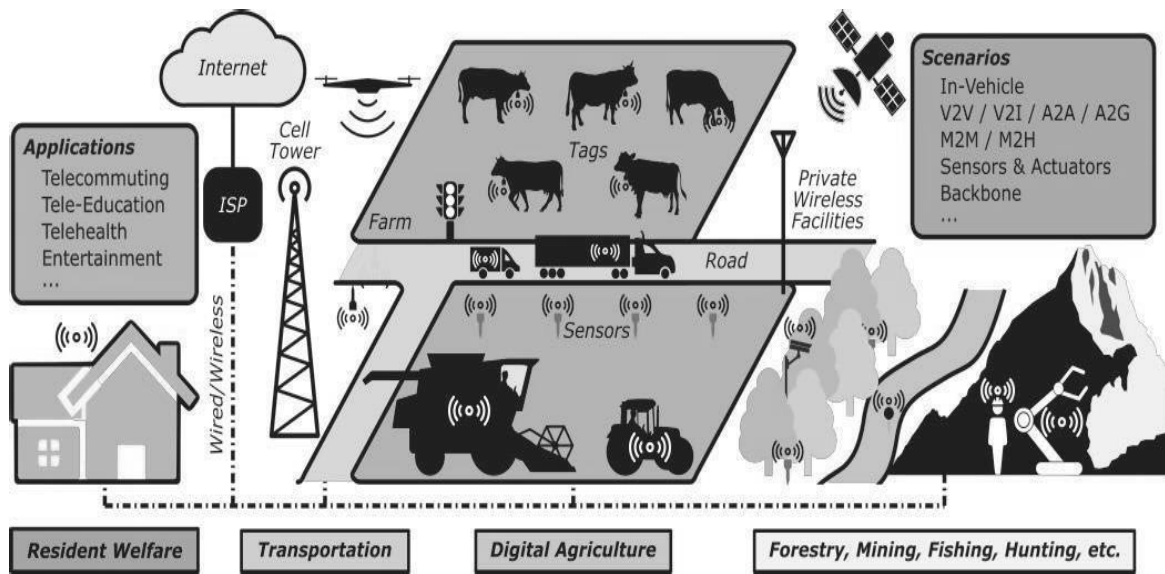


Figure 2.2: Demonstration of applications and opportunities for future wireless Communications (Yang et al., 2000).

2.2.2 Wireless Communication on Residential Welfare

Residential development contributes to people having a variety of housing options. It entails the subdivision and usage of land (to lots ranging in size from 2,500 m² to 1 hectare) to accommodate persons seeking to live in a semi-rural setting. The urban and rural Residential Development Strategy manages land proactively for residential use by designating 'clustered' development locations. In this way, it also contributes to the preservation of rural land balance for primary production and rural character (Wolfert et al., 2017). Implementing the Wireless Village program can help rural communities access and benefit from advancements in communication and information technology. Strong wireless connectivity can provide digital education, interact with social media, online entrepreneurship, online shopping, mobile banking, tele-health,

Broadcasting news, and entertainment (Govigli et al., 2020). Malaysia is advancing towards becoming a more connected, educated, and culturally proficient nation, aiming to achieve the government's goal of transforming the country into a high-income economy (Abdullah, 2017).

2.2.3 Wireless Connectivity for Transportation

Transportation systems in rural areas differ from those in metropolitan areas in terms of both features and requirements. According to Figure 2.3 , progressive rural transport systems (ARTS) test and install suitable intelligent transport systems (ITS) technologies, many of them require communication support, to address concerns about safety and efficiency in rural locations (Kumar et al., n.d.).

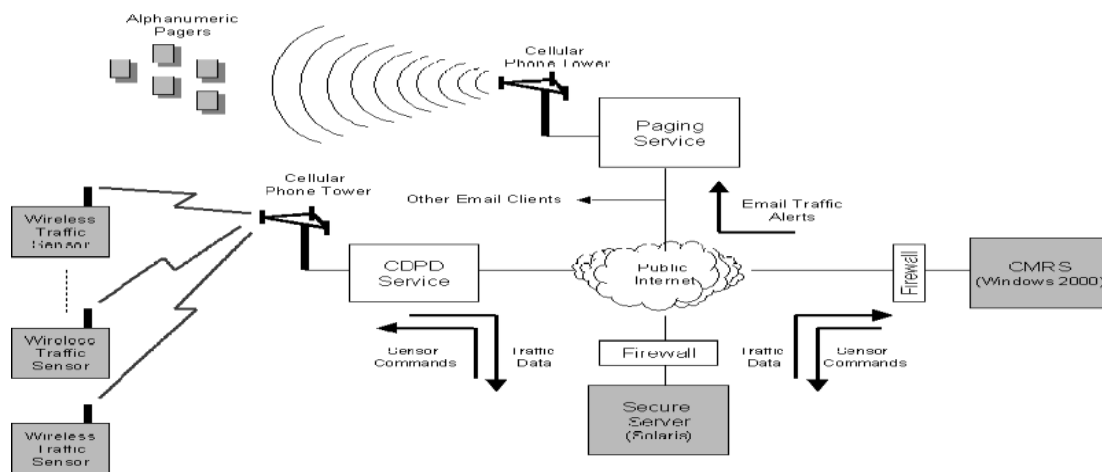


Figure 2.3: System architecture of ITS in Rural Areas by using Wireless Network (Kumar et al., n.d.)

The Traffic Operations Centre (TOC) can locate traffic through the presence of a central tracking and communication station. Sensors can be placed anywhere in the network where surveillance of traffic is required and still collect, log, and process data, as well as broadcast traffic information without the need for time-consuming processes (Kumar et al., n.d.).

2.2.4 Wireless Network Communication Based Digital/Smart Agriculture in Rural Areas

Precision Farming to linked, knowledge-based farm production systems is described as the revolution in agriculture and technological advances in agriculture as digital farming. Innovative precision farming technology is used in digital farming, but it also makes use of data management systems and intelligent networks. The goal of advanced farming is to apply all available information and expertise to automate sustainable farming operations (Campbell & Mackay, 2009).

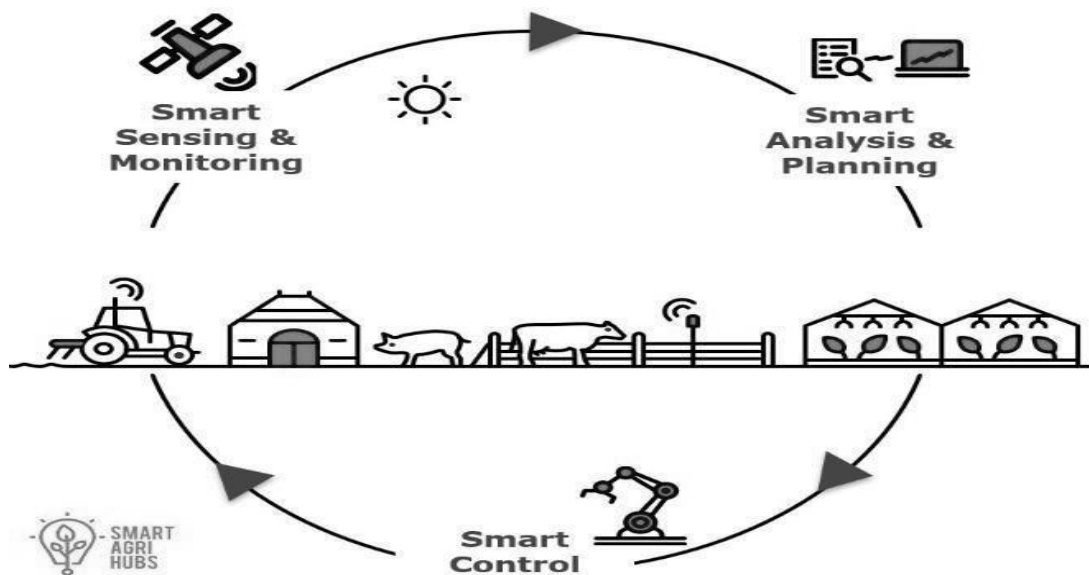


Figure 2.4: Broadband on digital farming by using IoT (Campbell & Mackay, 2009)

Form figure 2.4, broadband on agricultural land, as well as a general agricultural policy for how digital farming may benefit farmers, will be required. This represents a network that connects solution providers, training specialists, and researchers to one another as well as individuals and businesses in need of information sharing, innovative solutions, and matchmaking. Smart Agri-hubs meets the bill as an innovator in establishing the relationship (Mahmoodha & Dorathy, n.d.). In some sectors, digital farming is already a

reality, for instance, GPS navigation systems can be utilized for traffic farming management, targeted fertilization, or crop protection, all linked together in an all-encompassing production and input cycle through proprietary cloud-based connectivity. Smart farm monitoring systems based on IoT that take consideration multiple wireless connection technologies and parameters. In the agriculture industry, these techniques provide cost-effectiveness, extensibility, and reliability by utilizing mesh and star topology architectures. Most traditional systems use Wi-Fi and HC-12 wireless technologies to communicate sensor data from the agriculture field to the farmer (Al-Mumen & Hamad, 2022).

2.2.5 Forest Internet of Things (IoT) Using Wireless Network Communication

A smart forest monitoring system employs IoT and wireless communication technologies like LPWAN, LoRa, and NB-IoT. Figure 2.5 showed that To monitor various forest conditions, including light intensity, air pressure, UV levels, and CO₂, a solar-powered micro-weather station with LoRa-based sensors and communication capabilities has been created (Triezenberg et al., 2016).

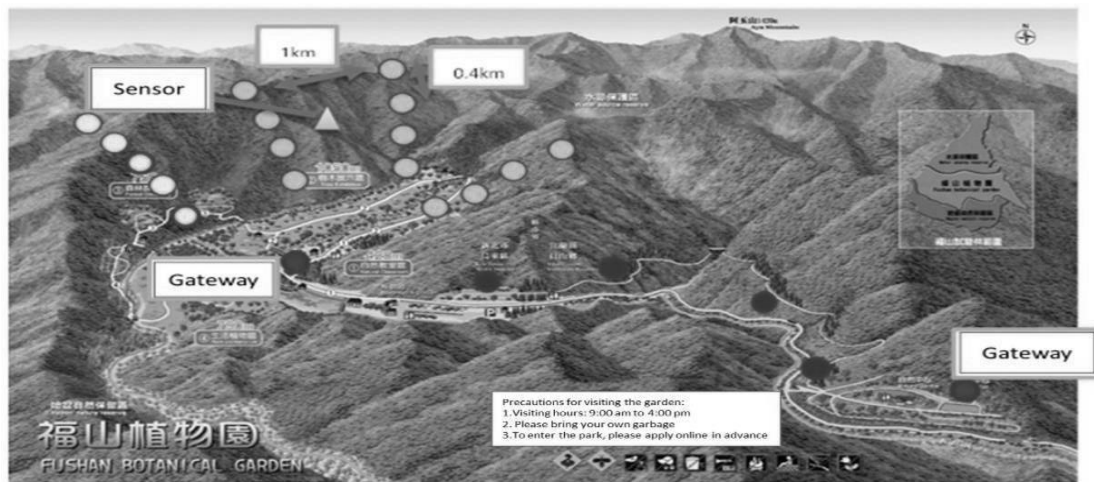


Figure 2.5: Realization of multiple LoRa-support solar micro-weather stations with repeat stations, and communication technology (Triezenberg et al., 2016).

From figure 2.6, Wireless Sensor Networks (WSN) can collect essential environmental data for decision-making in areas like forestry. By deploying a WSN in forests, it becomes possible to gather crucial ecological variables that aid in risk assessment and fire detection (Rana & Smieeee, 2022).

① Monitoring region, ② Wireless sensor module, ③ LoRaWAN gateway, ④ 4G/LTE link, ⑤ Server, ⑥ Control center, and ⑦ Detection support system (Rana & Smieeee, 2022). The data is transmitted wirelessly using the LoRaWAN protocol to a Lorix One gateway from Wifi. This gateway then forwards the data through an Ethernet connection, which is accessible at the gateway location via a 4G/LTE modem, to The Things Network (TTN) server (Rana & Smieeee, 2022).

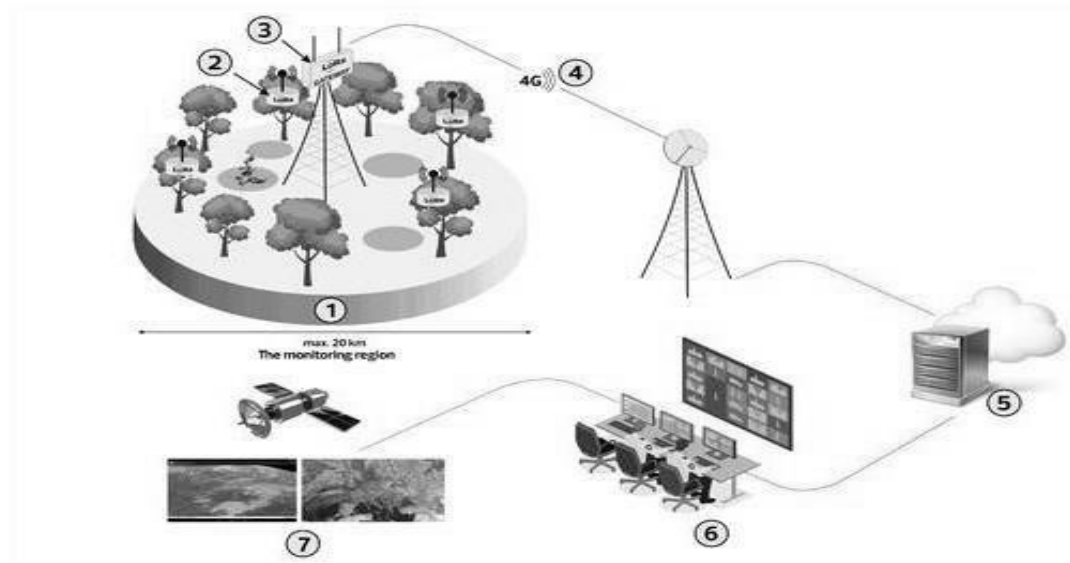


Figure 2.6: Illustration of Forest Alert Monitoring System (SAFE) System Architecture

2.2.6 Wireless Communication Technologies for Advanced Underground Mining Operations

Mining has consistently relied on new technologies to enhance production, boost safety, minimize environmental impact, and lower operational costs. The industry confronts several challenges, including decreasing ore grades, complex deposit structures, and volatile

commodity prices, which are fueling the need for digital transformation. The ultimate goal of mining digitalization is to create a connected, autonomous mine where decisions are made in real-time based on data (Rana & Smieeee, 2022).

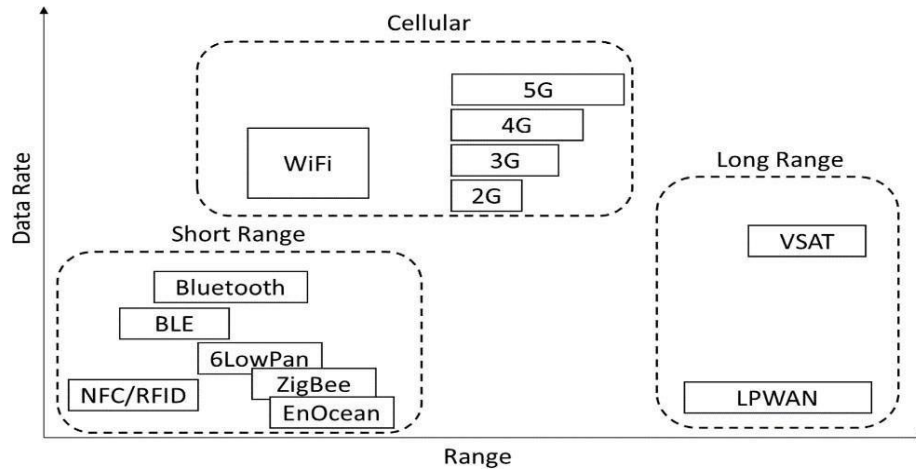


Figure 2.7: Data Rate Vs. (Aboveground) Radio Communication Technologies at Mining Sector (Al-Mumen & Hamad, 2022).

Wireless communication technologies above ground are usually implemented as general infrastructure that is available to everyone, often with provider-based fees. This infrastructure exists not only as public resources but also as private networks within businesses, campuses, or institutions. Typically, it is set up as a multi-layered communication system in both rural and urban settings that showed in Figure 2.7 (Al-Mumen & Hamad, 2022).

2.2.7 Wireless Network Communication for Fishing and Hunting

Wireless communication becomes very famous for fishing nowadays because, wireless headsets are quickly becoming common equipment for fishing on the river or sea. Fishers can converse in normal tones with their partners, from boat to boat. Even on a charter operation, skippers can maintain fisher privacy for smoother professional communication, but they occasionally provide customers with radios so they can participate in the

conversation (Tabassum et al., n.d.). On the other side, to get the weather condition during fishing is very important to fishers for their safety of lives and properties. Radio communication playing avital role for fishing at rural area. Even by mobile communication it helps them marketing their fishing business.

Communication is one of the most important factors to consider when hunting. To coordinate your efforts, be safe, and be successful, hunter must be able to communicate with hunting partners. There are several communication possibilities, each with its own set of advantages and downsides. Two-way radios are one method of communication. Because they allow users to communicate over long distances, two-way radios are a popular choice for hunting partners. These are also reasonably priced and simple to use. Radio communications have always been an advantage. It is possible to shorten the distance by having a friend who can communicate clearly and quietly with you along the way. Wireless communications have always been beneficial. It is easy to reduce the distance by moving with a friend who can converse effectively and slowly with you (Bisht et al., 2019). Some wireless devices are using for navigation to be tracking the prey in jungle to ease the hunting.

2.3 Microstrip Antenna Important parameters and Configurations

Microstrip antennas are widely favoured for their slim design, light weight, and simple manufacturing process. These antennas generally comprise a metal patch on a grounded substrate. Several factors, such as the patch's shape and size, the substrate material, and the chosen feeding technique, can affect the characteristics of microstrip antennas, including impedance, bandwidth, and radiation pattern.

2.3.1 Different Types of Feeding Techniques

Designed of antenna is one of the problems of the causes. Common feeding technique causes mutual coupling with the arrays and interrupt to get the wanted frequency/signal clearly. From figure 2.8, recent research in Feeding of antenna can divide by contacting and non-contacting. (Gupta & Chawla, 2016).

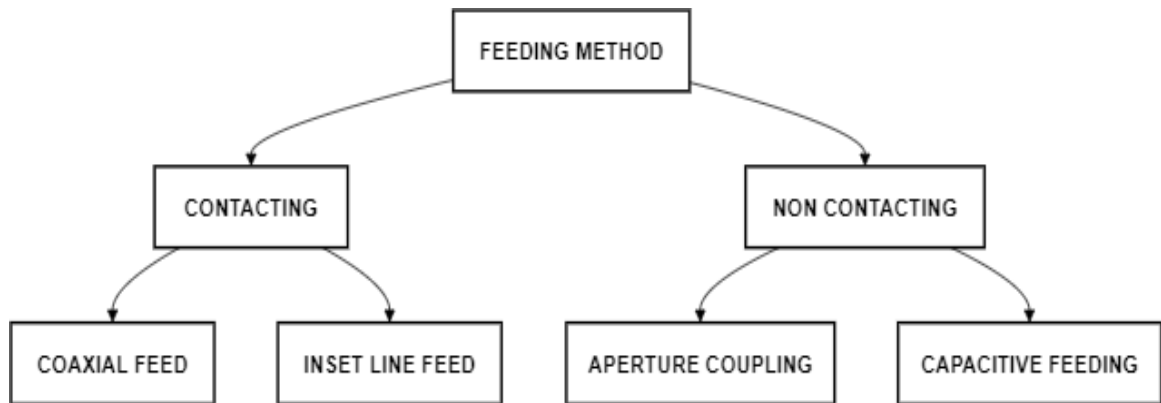


Figure 2.8: Feeding Method of Microstrip Array Antenna (Gupta & Chawla, 2016)

2.3.2 Frequency

To understand frequency, it is essential to examine electromagnetic waves, which consist of an electric field radiating from the antenna. These waves are periodic and vary with both position and time. Frequency measures the rate at which these waves oscillate. In this design, frequency indicates the wavelength at which the antenna operates or its range (Petrov et al., 2017). Additionally, the power transmitted by an antenna is categorized into different frequency regions or bands.

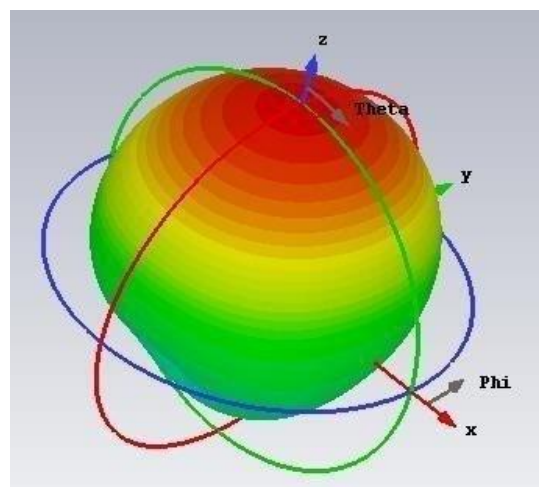
2.3.3 Fringing Effect

Fringing fields significantly influence the performance of a microstrip patch antenna. Because of the patch's limited size, the fields at the edges experience fringing, which is affected by the patch dimensions and substrate height; a thicker substrate enhances fringing.

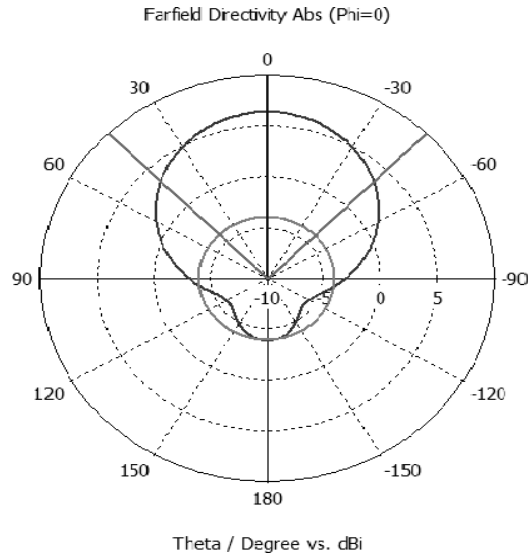
In microstrip patch antennas, the electric field is zero at the center. Fringing makes the antenna seem larger than its actual physical size. To achieve the desired resonant frequency, microstrip patch antennas are generally designed with a 2-4% size reduction (Aghaedah & Oti, n.d.).

2.3.4 Radiation Pattern

A radiation pattern characterizes how an antenna's emitted power varies across different directions. It shows the strength of the radiated field at a fixed distance and provides insights into the antenna's receiving capabilities (Prados-Garzon et al., 2017). While the pattern is inherently three-dimensional, it is usually measured in two-dimensional slices along vertical and horizontal planes. From figure 2.9 (a) & (b) These patterns can be displayed in either rectangular or polar formats. The rectangular format may complicate the visualization of the antenna's performance from various angles, whereas the polar format, which uses a polar coordinate system, is more commonly used. Radiation patterns can be categorized into two types: linear and logarithmic. They can also be classified in two ways: as absolute radiation patterns or relative radiation patterns.



(a)



(b)

Figure 2.9: (a) 3D Format and (b) 2D Polar Format of Radiation Pattern (Prados-Garzon et al., 2017).

2.3.5 Return Loss

Return loss is a crucial parameter and key measurement for antennas. It assesses the overall performance of the system and indicates whether the antenna will operate within the desired frequency range. Return loss reflects how effectively an antenna can transmit power from the source. Essentially, return loss measures the loss of reflected power (J. Zhang et al., 2017). In telecommunications, return loss refers to the power lost due to reflections caused by discontinuities in a transmission line, known as impedance mismatches. These mismatches result in two signals traveling along the cable: one in the forward direction and one in the reverse, which can interfere with each other and lead to data loss at the receiving end. Thus, return loss is a significant concern in transmission lines.

From figure 2.10, return loss is typically expressed in dB and is also referred to as the $S_{1,1}$ parameter. This parameter measures the power reflected from the antenna. An $S_{1,1}$ of 0 dB indicates that all power is reflected back, meaning the antenna is not radiating.

Conversely, an $S_{1,1}$ of -10 dB implies that if the power delivered to the antenna is -3 dB, then -7 dB of power is reflected. The ratio of reflected power to incident power is denoted by Γ in equation 2.1.

$$\text{Return Loss} = -20\text{Log}_{10}\Gamma \text{ (dB)} \quad \text{Equation 2.1}$$

Γ = Reflected power / Incident power.

To ensure efficient power transfer, the ratio needs to be high. If not, resonances might occur, leading to frequency fluctuations.

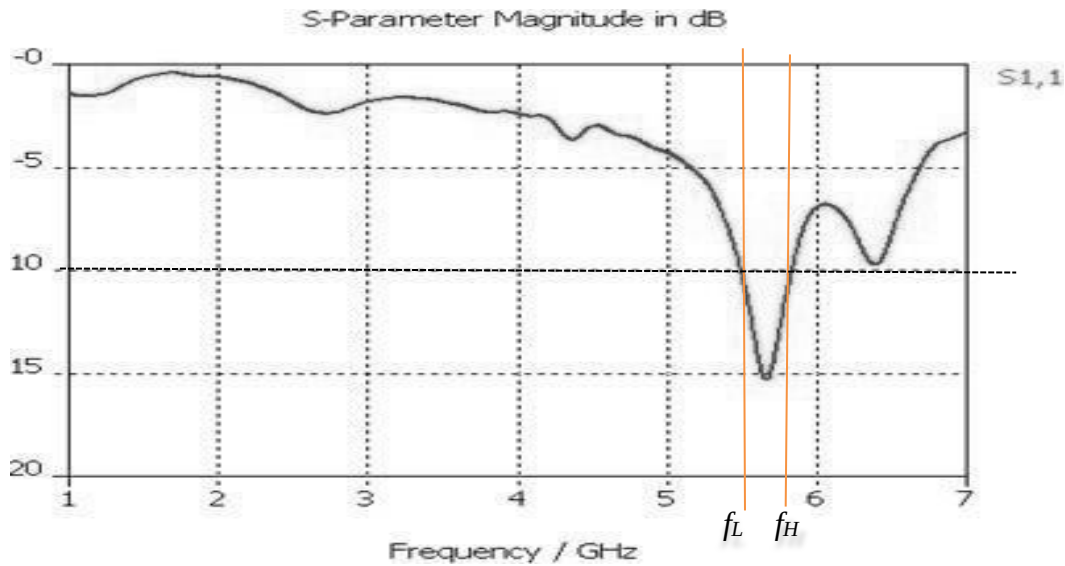


Figure 2.10: Return Loss of Microstrip Antenna

2.3.6 Directivity

Directivity is a fundamental parameter of an antenna, representing its radiation pattern and indicating how directional it is. For instance, an antenna that radiates equally in all directions has zero directivity. The shape of the radiation pattern determines the antenna's directivity. Directivity can be less than one and can even be zero.

2.3.7 Gain of an Antenna

Antenna gain essentially reflects the performance of the antenna. It is closely related to directivity, but unlike directivity, gain also depends on both efficiency and directivity shown in equation 2.2. Typically expressed in dB, the desired gain level can vary based on the specific application. Genetic algorithm optimization of a high directivity microstrip patch antenna having a rectangular profile. For instance, if the signal source is well-known, a high antenna gain is preferable. Conversely, if the signal source is less predictable, a lower gain is more suitable. For instance, Wi-Fi and television antennas typically exhibit higher gain, whereas GPS and cellular antennas tend to have lower gain.

$$G = \epsilon D \quad \text{Equation 2.2}$$

Where G = Gain and D = Directivity.

2.3.8 Bandwidth

Bandwidth refers to the range of frequencies within which an antenna can effectively transmit or receive energy. It defines the span of frequencies over which the antenna performs within specified parameters for various characteristics. Bandwidth is a critical consideration when selecting an antenna (Al-Mumen & Hamad, 2022). It is commonly expressed in terms of the Voltage Standing Wave Ratio (VSWR). For narrowband antennas, bandwidth is the range of frequencies centered on the midpoint frequency. For broadband antennas, it is the ratio between the maximum and minimum operational frequencies. Bandwidth measurement is described by equation 2.3.

Percentage bandwidth,

$$BW = \frac{f_h \times f_L}{f_o} \times 100\% \quad \text{Equation 2.3}$$

f_h = High frequency

f_L = Low frequency.

f_o = Frequency of operation (5.8 GHz)

2.3.9 Antenna Efficiency

Efficiency is a crucial factor for an antenna, ensuring that it effectively utilizes all the power and energy provided by the source. It evaluates the losses within the antenna structure and at its terminals. Essentially, efficiency is the ratio of the total power radiated by the antenna to the total input power supplied to it. It is clear that no antenna can achieve 100% efficiency due to inherent losses. Efficiency can be compromised by mismatches between the transmission line and the antenna, as well as dielectric or conductivity losses. High efficiency means the antenna radiates most of the power delivered to it, while low efficiency indicates that power is either absorbed as losses at the antenna terminals or reflected away due to impedance mismatch.

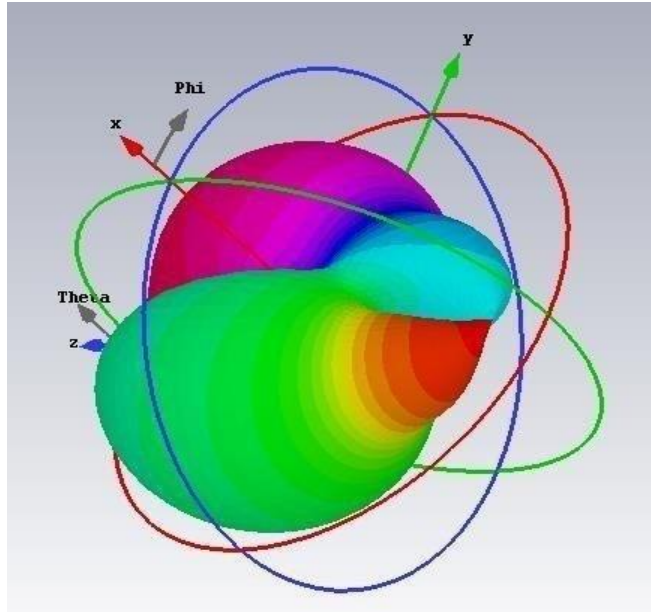
2.3.10 Polarization

Polarization is a crucial aspect in antenna design, affecting both RF antennas and electromagnetic waves. Understanding antenna polarization involves examining the properties of the radiated fields, which are fundamental characteristics of electromagnetic waves. These waves are defined by the varying direction and magnitude of the electric field vector. For optimal signal reception, the polarization of the receiving antenna must match the orientation of the radiated field. When there is a mismatch in polarization between transmitting and receiving antennas, it leads to polarization mismatch and power loss. To

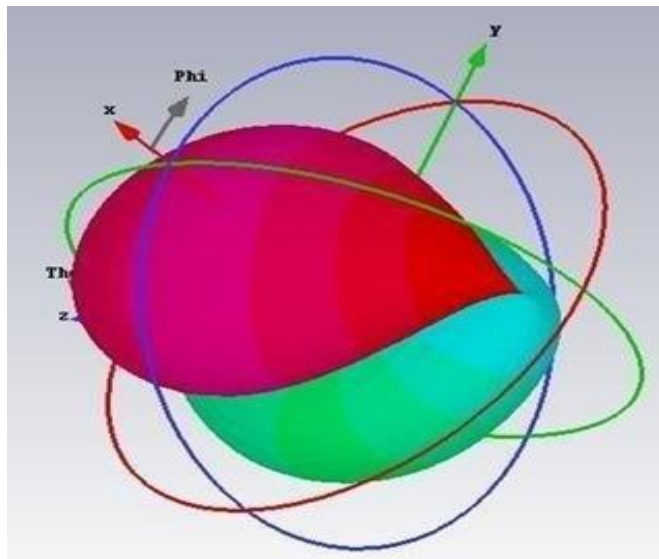
reduce power loss, the polarization directions must align. The concept of polarization loss factor, also known as polarization efficiency, antenna mismatch factor, or antenna receiving factor, addresses this issue (Hamoudi et al., 2013). Antenna polarization can be categorized into three types: linear, circular, and elliptical. Linear polarization occurs when the electric and magnetic fields of the antenna are aligned in a single direction, perpendicular to each other. If the electric field is parallel to the Earth, it is horizontally polarized; if perpendicular, it is vertically polarized.

Circular polarization happens when the electric or magnetic field vector rotates in a circular path while maintaining a constant length. This can be clockwise (right-handed circular polarization, RHCP) or counter clockwise (left-handed circular polarization, LHCP). A notable aspect of circular polarization is that RHCP waves reflected from surfaces can act like LHCP waves, which can lead to signal fading due to the reflected waves blocking desired signals. This is why GPS satellites often use RHCP signals.

Elliptical polarization occurs when the end of the electric or magnetic field describes an elliptical trajectory in space. Unlike circular polarization, where the perpendicular components have equal amplitudes and a 90-degree phase difference, elliptical polarization involves components with differing amplitudes while maintaining the 90-degree phase difference. The phase shift and amplitude ratio are consistent and determined by the amplitudes of the major and minor axes. Different types of polarization based on Theta and Phi phases are depicted in Figure 2.11.



(a)



(b)

Figure 2.11: Different types of polarization (a) Theta phase and (b) Phi phase [40]

2.3.11 Substrate

There are types of substrates which can be used design a microstrip patch antenna. Most common substrate properties are:

FR-4 dielectric substrate: FR-4 is a popular material used in making printed circuit boards (PCBs). It's basically made from fiberglass cloth soaked in epoxy resin, which makes it sturdy and fire-resistant. This fire resistance is a big deal and one of the main reasons it replaced the older G-10 material, which could catch fire more easily. For electronics operating under 1 GHz, FR-4 does a great job. But working with higher frequencies, especially between 3-6 GHz, things get a bit more complex. That need to think about factors like how the signal travels on the surface of the material (skin effect), the roughness of the surface, how nearby conductors affect each other (proximity effect), and the properties of the dielectric material itself. FR-4's dielectric constant, which affects how it stores and transmits electric energy, usually falls between 4.3 and 4.8 and can vary a bit with frequency. Its loss tangent, which indicates how much signal power is lost as heat, is 0.018 (U. Ali et al., 2023).

RT/Duroid 5880 dielectric substrate: RT/Duroid 5880 is a special material made by Roger Corporation, ideal for high-performance stripline and microstrip line applications. It's a composite of glass microfibers and PTFE (similar to teflon), making it durable and versatile. This material is known for its excellent resistance to chemicals, including solvents and reagents used in printing and coating processes. It's also easy to cut, shape, and machine, which makes it very user-friendly and environmentally safe. One of the standouts features of RT/Duroid 5880 is its very low loss tangent of about 0.004, meaning it doesn't lose much

signal as heat. It also has a dielectric constant of 2.2, which is great for high-frequency applications (Miftahul Amri & Ramadhan Faqih, 2022).

RO3003 dielectric substrate: RO3003 laminates are a type of circuit material made from a ceramic-filled PTFE (similar to Teflon) composite. One of the cool things about this material is that its mechanical properties stay the same no matter what dielectric constant you choose. This means designers can create multi-layer boards with different dielectric constants for each layer without worrying about accuracy issues. RO3003 is known for having a very low loss tangent of 0.0013, which means it hardly loses any signal as heat. It also has a dielectric constant of 3.0, making it a great choice for precise and efficient high-frequency applications (Kuschel et al., 2010).

Dielectric constants typically range from 2.2 to 12 for these materials. An antenna initially radiates due to interactions at the patch edge and ground plane. For broadband microstrip antennas on high-dielectric substrates, using a genetic algorithm can be beneficial (Nurvitasari et al., 2014). The loss tangent measures the amount of electrical energy converted into heat by the dielectric, impacting antenna efficiency. While a higher dielectric constant is preferred in microwave circuitry to minimize coupling and unwanted radiation, it can lead to reduced efficiency and narrower bandwidth due to increased losses. Therefore, achieving a balance between effective circuit design and performance often requires a higher dielectric constant.

2.4 Microstrip Patch Array Antenna

2.4.1 Different Shapes of Microstrip Antennas

Microstrip patch antennas can be categorized based on their physical dimensions and shapes. Various patch types serve different purposes, including square, rectangular, circular,

dipole, triangular, disc sector, ring sector, printed, and elliptical configurations (Sunitiyoso et al., 2023). Some of these shapes are illustrated in Figure 2.12. Additionally, patch antennas can include different slot configurations, such as A-slot, U-slot, H-slot, and E-slot, each designed for specific frequency bands.

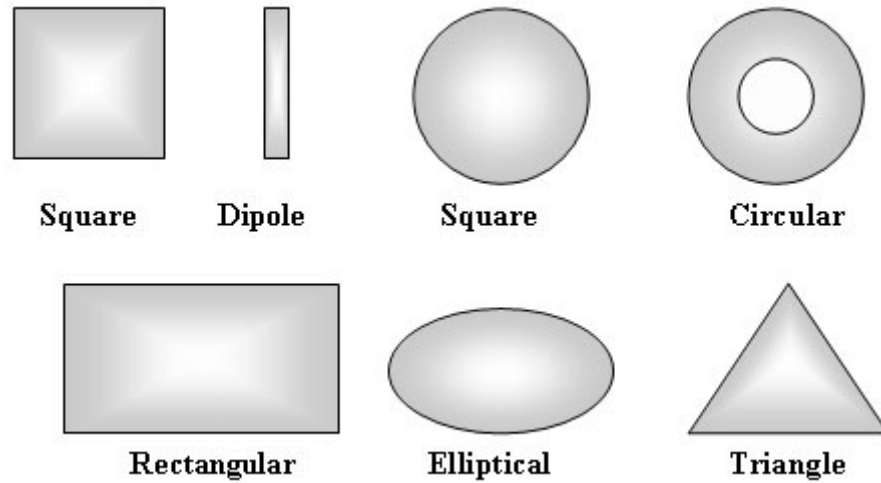


Figure 2.12: Configuration of different shapes of array patch antenna (Sunitiyoso et al., 2023)

2.4.2 Improvement of Microstrip array Antennas at 5.8 GHz

Since the 1970s, microstrip antennas have gained popularity and are now widely used in both government and commercial sectors. These antennas consist of a metallic copper patch and a ground plane separated by a thin dielectric sheet known as the substrate. The copper patch, which serves as the radiating element, is usually photo-etched onto the dielectric material. The patch can come in various shapes, such as square, rectangular, circular, dipole, or elliptical. Circular and rectangular patches are particularly favoured due to their straightforward fabrication, ease of analysis, and effective radiation characteristics, including minimal cross-polarization radiation (Knott, 2013). The rise of wireless and

mobile radio communications has significantly increased the demand for microstrip antennas (khalil Ibrahim & Jebur, 2021; Knott, 2013). These antennas offer several advantages, including a low-profile, versatile structure, simplicity, and cost-effectiveness in manufacturing. They are easily adaptable to both planar and non-planar surfaces and can be manufactured using PCB technology (Kyei et al., 2017). Additionally, microstrip antennas can be mounted on high-performance, stringent surfaces and are well-suited for MMIC designs.

2.4.3 Inset Feed Single Array Directional Antenna

The inset feed technique is a simple but very effective way of feeding a microstrip patch antenna. Instead of connecting the feed line at the very edge of the patch, the line is slightly cut or inset into the patch showed in Figure 2.13. This small shift helps to control the input impedance of the antenna, making it easier to match with the standard $50\ \Omega$ feed line. In other words, by carefully choosing how deep the inset goes, the mismatch between the patch and the feed is reduced, which improves return loss and overall antenna performance. This method is popular because it is easy to design, doesn't require extra components, and provides good control over impedance matching (Nour et al., n.d 2017.).

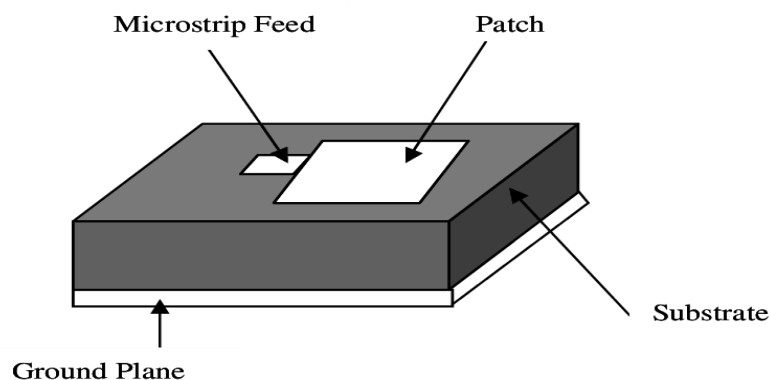


Figure 2.13: Inset Feeding Method of Microstrip Array Antenna (Nour et al., n.d.2017)

2.4.4 Coaxial Feed Array Directional Antenna

The feed can be placed at any suitable point on the patch to obtain the desired input impedance. The inner conductor of the coaxial cable connects to the patch by passing through the substrate from the ground showed in figure 2.14. This feeding technique is characterized by low spurious radiation. However, a drawback of coaxial feeding is the need to drill a hole into the substrate during fabrication. Additionally, radiation from the probe must be considered, as it could cause undesirable effects (Li & Schreurs, 2017).

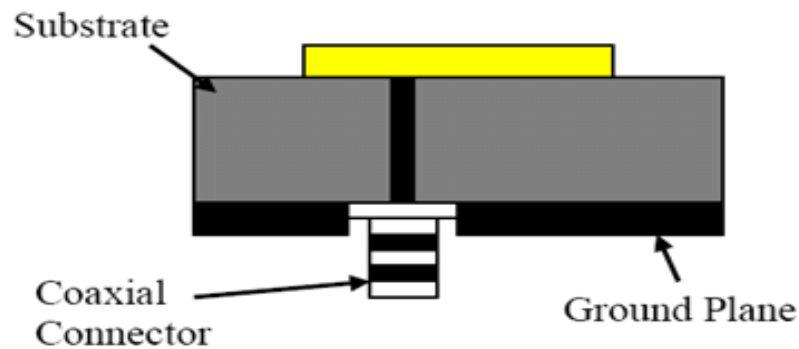


Figure 2.14: Coaxial Feed method of microstrip array antenna (Li & Schreurs, 2017)

2.4.5 Aperture Coupled Feed Array Antenna

This feeding method is non-contacting, isolating the patch's radiation from the feed line. The fundamental design of a microstrip patch antenna using this feeding technique involves two dielectric materials showed in figure 2.15. The benefits of this antenna include minimal spurious radiation, improved bandwidth, and reduced interference. Usually, a material with a lower dielectric constant is selected for the upper substrate, while a material

with a higher dielectric constant is chosen for the lower substrate to enhance the patch's radiation (Ranjan & Mishra, 2013).

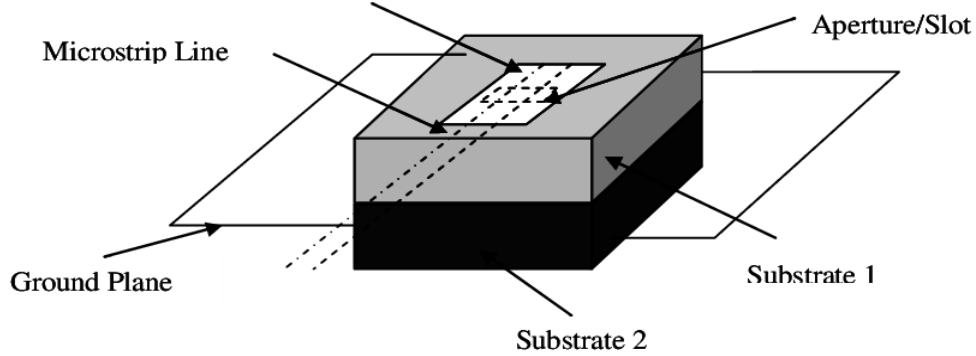


Figure 2.15: Aperture coupled feed method of microstrip array antenna (Ranjan & Mishra, 2013)

2.4.6 Proximity Coupled Feed Array Antenna

Proximity coupling uses a dual-layer substrate, where the microstrip line is placed on the lower layer and the patch antenna on the upper layer showed in figure 2.16. Adjusting the parameters of these two substrate layers can improve bandwidth. This feeding technique can increase bandwidth performance by up to 200 MHz (22%) at a center frequency of 900 MHz (Kumari et al., 2014).

Low efficiency, narrow bandwidth under 5%, and reduced RF power due to the minimal gap between the radiating patch and the ground plane negatively impact the antenna's bandwidth performance.

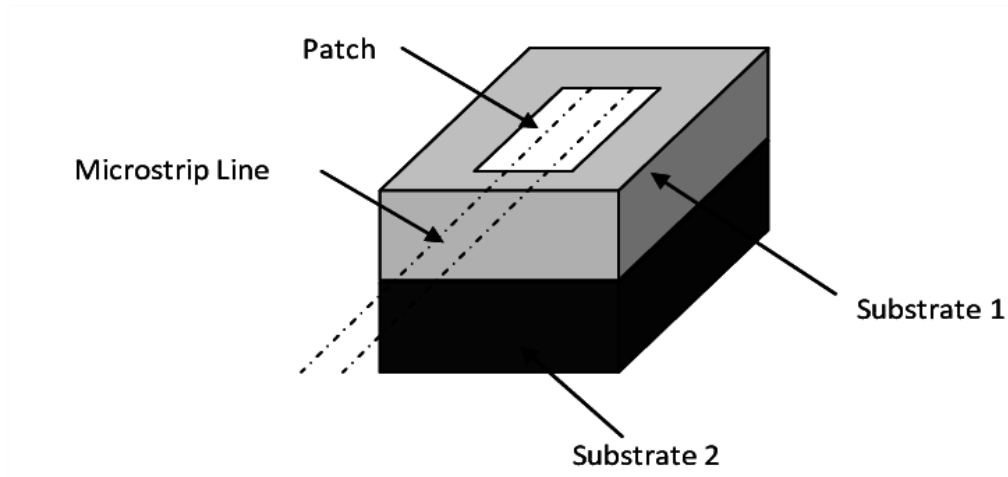


Figure 2.16: Proximity coupled feed method of microstrip array antenna (Kumari et al., 2014)

2.4.7 Characteristic of Different Feed Techniques

For designing a microstrip patch antenna with different feeding techniques it can be provide different results and different structure, different bandwidth, and different method of the fabrication (J. D. Kraus, 2007). Characteristic of different feeding techniques is shown in Table 2.1.

Table 2.1: Characteristic of Different Feeding Techniques

Characteristic	Microstrip Line Feed	Coaxial Feed	Aperture Couple Feed	Proximity Couple Feed
Spurious radiation	More	More	More	More
Ease of fabrication	Uncomplicated	Soldering and drilling required	Alignment necessary	Alignment necessary

Table 2.1 continued

Impedance matching	Uncomplicated	Uncomplicated	Uncomplicated	Uncomplicated
Reliability	Better	Poor due to soldering	Good	Good
Bandwidth	2-5%	2-5%	2.1%	2.13%

From Table 2.1, it can be easy to know which feed technique is suitable to use in microstrip antenna to get better performance of $S_{1,1}$ parameter in respective applications. Before we get into the specifics of the $S_{1,1}$ parameter, it's important to understand S-parameters, or scattering parameters, and why they matter in RF and microwave engineering. S-parameters describe how RF signals behave in a network, especially in terms of transmission and reflection at various points. These parameters are key for evaluating how well components like antennas, amplifiers, and filters perform in terms of signal behaviour.

2.4.8 Performance of Microstrip Antenna through Inset Feed Method

Although advancements in Microstrip Patch Antennas (MSA) and MSA arrays (MSAA) have largely been driven by military and space needs, their commercial applications are growing rapidly. Key features of MSA/MSAA include radiation pattern, beam width, directivity, gain, bandwidth, quality factor, efficiency, polarization, and return loss. Military and space applications often demand the highest performance, regardless of cost. In contrast, commercial uses tend to prioritize cost-effectiveness, which might involve some trade-offs in electrical performance (khare et al., 2010). Moreover, 5th generation (5G)

wireless systems will use numerous smaller cells to handle traffic from cellular and other wireless networks (Kapusuz et al., 2018). A significant aspect of 5G technology is its adaptable frequency spectrum, which supports various applications across low-band (below 1 GHz), mid-band (1 GHz to 6 GHz), and high-frequency bands (above 6 GHz) (Misra et al., 2015). The variety in patch shapes caters to different uses, and improvements in dielectric materials and design methods have greatly enhanced the popularity of MSA (Aktar et al., 2020).

2.4.9 Microstrip array antenna for 5G mobile communication at 5.8 GHz

5G represents the next generation of mobile communication systems designed to address communication needs beyond 2020. This new generation is expected to deliver significant improvements in spectral and energy efficiency. Compared to 4G, 5G will offer a substantial increase in transmission rates and resource utilization, potentially by an order of magnitude or more (Amit Kumar, Jaspreet Kaur, 2013). Additionally, it will enhance wireless coverage, reduce transmission delays, improve system security, and elevate user experience. The integration of 5G with other.

Wireless technologies will lead to the creation of advanced, ubiquitous mobile information networks. Consequently, 5G has become a major focus of research and development worldwide, with many countries working to advance network performance, security, and user experience (Sandi et al., 2020). One approach to address issues in antenna arrays is by employing frequency selective surfaces (FSS) to modify radiation characteristics like bandwidth, gain, and directivity. Alternatively, optimization techniques can be used to design single-element antennas that match the performance of arrays but with a smaller patch area (A. Rahman and N. T. Nasir, 2022). Microstrip antenna arrays are increasingly utilized

in telecommunications, including satellite communications (Lova Raju & Vijayaraghavan, 2022), L-band networks for GNSS/GPS, wireless sensor networks, and textile substrates for body-centric communications (Zhao et al., 2023). Recent research has also explored the use of multilevel fractal geometry in microstrip arrays to achieve high directivity and reduce array size and feeding network complexity (Brito et al., 2020).

2.4.10 Directional Microstrip array Antenna at UHF-Band for Passive Radar Application

Passive radar is an electromagnetic system that detects and tracks targets by receiving reflected frequency signals from external sources like radio stations, TV broadcasters, or mobile communication base stations. The antenna plays a crucial role in passive radar by capturing these frequency signals. Typically, passive radar antennas are large microwave types and need to be strategically positioned. This study focuses on developing a passive radar antenna using a microstrip antenna (Theissen et al., 2023). Microstrip antennas are favoured in various applications due to their lightweight, compact, thin, and cost-effective nature, making them known as low-profile antennas (Y. Zhang et al., 2021). For passive radar, the antennas use signals from TV transmitters, operating in the UHF band (476-806 MHz) (Aji et al., 2016), which aligns with Indonesia's TV broadcast frequency regulations. While Peter Knott has previously designed microstrip antennas for passive radar using an array approach for higher gain (Mazen et al., 2021), this research will employ a director and reflector setup to achieve substantial gain.

2.4.11 2x2 Directional Microstrip Array Antenna

Microstrip patch antennas face challenges such as low gain and bandwidth, which can be mitigated by utilizing a thick dielectric substrate with a low dielectric constant to improve bandwidth and radiation patterns (Ya et al., 2021). However, this approach also

leads to an increase in the antenna's overall size. To overcome these limitations, patch antennas are often arranged in an array, which boosts gain, bandwidth, and radiation patterns (Vera Dimas et al., 2019).

Before designing the microstrip antenna, it is crucial to determine the specifications and materials. In this study, we use FR-4 as the substrate, which has a dielectric constant of 4.4 and a thickness of 1.6 mm. To calculate the dimensions of the microstrip patch antenna, applied equation 2.4, and the patch length is derived using equations (2.4) through (2.13). The width of the patch microstrip antenna is calculated with the provided equation.

$$W = \frac{C}{2\varepsilon_r} \times \sqrt{\frac{2}{s+1}} \quad \text{Equation 2.4}$$

Where

W = Width of the patch

C = Speed of the light in free space (3×10^8 m/s)

ε_r = Dielectric constant

$$C = \frac{C}{2f_o \sqrt{sr}} - 2\nabla L \quad \text{Equation 2.5}$$

Where

$$\nabla L = 0.4212h sre - 0.2 \frac{\frac{w}{h} + 0.2}{\frac{w}{h} + 0.8} \quad \text{Equation 2.6}$$

Where

$h = \text{height of the substrate and } \epsilon_r$

$$\epsilon_r = \frac{S_r + 1}{2} + \frac{S_r + 1}{2} \left[1 + 12 \frac{w}{h} \right] - 0.5 \quad \text{Equation 2.7}$$

The ground plane dimensions, including length L_g and width W_g , for a microstrip antenna can be determined using equations (8) and (9)

$$L_g = 6h + L \quad \text{Equation 2.8}$$

$$W_g = 6h + w \quad \text{Equation 2.9}$$

The feed width W_r is calculated to achieve a characteristic impedance of 50 Ω .

$$w_o/h = 2/\pi + [B - 1 - h(2B - 1)(\epsilon_r - 1)/(2\epsilon_r)] + (h(B - 1) + 0.39 - 0.61/\epsilon_r) \quad \text{Equation 2.10}$$

Where

$$B = \frac{3\pi}{2Z_o\sqrt{s_r}} \quad \text{Equation 2.11}$$

And formula of the length a feed antenna

$$L = \frac{\lambda_g}{4} \quad \text{Equation 2.12}$$

Where

$$\lambda = \frac{\lambda_o}{\sqrt{s_r}} \quad \text{Equation 2.13}$$

2.4.12 Previous Related Works and SOTA Table

Mentioned by previous researcher, mutual coupling in antenna arrays is not only caused by radiation interaction between elements but also significantly influenced by the feeding network. As noted by Gu et al. (2024), feed lines act as additional coupling paths since surface currents on these lines can leak into adjacent elements. Zhang et al. (2023) further confirm that the electromagnetic fields generated by the feeding structure may extend beyond the target element, producing unintended coupling. Similarly, Shirpay et al. (2023) highlight that the substrate-feed interface excites surface waves, which propagate and reach neighbouring patches. Moreover, research on circular patch arrays at 5.8 GHz demonstrates that feeding lines also induce coupling through the ground plane, which can be mitigated using defected ground structures (DOAJ, 2023). Despite the advancements presented in the paper "A 2 by 2 planar array antenna using aperture coupler technique" by M. T. Ali et al., there remain several areas that warrant further exploration. The study focuses on the design and performance of a planar array antenna using aperture coupling. The author introduced a technique called inset-feed for creating multi-band antennas, which helps improve return loss (basically, how much signal is reflected back). However, while it does fix that issue, the technique still has some downsides. The antennas made this way tend to have low gain (weak signal strength), low efficiency (not all the input power is effectively used), low directivity (the signal isn't focused well on a particular direction), and a narrow bandwidth (it can't handle a wide range of frequencies) (Tecpoyotl-Torres et al., 2013). On the other hand, the development and fabrication of a dual-antenna array designed to operate at 5.8 GHz, a frequency ideal for various uses, particularly within the ISM band and IoT applications. To improve performance metrics and minimize the array's size, the researchers utilized several advanced techniques.

The array, when implemented on a thin substrate, achieved a measured bandwidth of 617 MHz, covering the range from 5.503 to 6.120 GHz, which equates to 10.63% of the central frequency. Alternatively, using a thicker substrate, the measured bandwidth was 455 MHz, spanning from 5.517 to 5.972 GHz, or 7.84%. The simulated gains were 6.89 dBi and 7.63 dBi, while the actual measured gains were 6.7 dBi and 7.2 dBi, respectively. Furthermore, the array accomplished a size reduction of more than 30% and demonstrated simulated efficiencies greater than 90% (M. T. Ali, Alias, et al., 2011). In [67], a new design for a microstrip patch antenna with a unique layered structure. This antenna uses two radiating patch elements stacked on top of each other, each operating at different frequency ranges. Specifically, the top and bottom patches are designed to resonate at 5.8 GHz and 2.4 GHz, respectively. These frequencies cover both sub-6 GHz and 5G mm Wave ranges, making this design beneficial for advancing 5G communication technologies by supporting both 4G and 5G. The layered structure helps reduce surface radiation caused by the inset feed. To optimize performance, the antenna design includes a driven patch with a ring slot and a parasitic patch with a square slot. For the radiating elements, the project uses Rogers RT/Droid 5880 substrate with a thickness of 0.7 mm for low frequencies and 0.149 mm for high frequencies. Additionally, a Rogers RO4450F substrate with a thickness of 0.1 mm is used as an adhesive layer between the two radiating elements. Performance-wise, the proposed antenna achieves impressive results. It shows a low return loss of about -24 dB at 5.83 GHz and -36 dB at 24 GHz. The VSWR is approximately 1.13 at 5.83 GHz and 1.029 at 24 GHz, indicating good impedance matching. The antenna provides a bandwidth of around 100 MHz (from 5.772 GHz to 5.874 GHz) and 550 MHz (from 23.707 GHz to 24.257 GHz). Additionally, the antenna demonstrates high directivity (6.7 dBi at 5.8 GHz and 7.8 dBi at 24 GHz) and effective side-lobe suppression (- 20.3 dB and -2.5 dB). The design and

simulation of an efficient energy harvesting device that converts radio frequency (RF) signals into usable DC voltage. The device incorporates microstrip antennas, matching circuits, and rectifiers. Both single patch and array antennas were developed to operate specifically at 5.8 GHz, using simulation tools like CST Studio and Advanced Design System (ADS). Results showed promising performance metrics with acceptable return loss and high gain.

To further enhance energy capture, an array of microstrip antennas was utilized. The rectifier circuit, employing a voltage doubler and Schottky diodes, efficiently converted RF energy to DC output voltage. A crucial aspect of the design involved optimizing the matching circuit to achieve a $50\ \Omega$ impedance, essential for maximizing energy transfer efficiency. The device achieved an impressive output voltage of 6.2 V when subjected to an input power of 20 dBm and connected to a $560\ \Omega$ load resistance. The increasing demand for portable devices with low power consumption, such as IoT sensors and nano-devices, underscores the importance of efficient energy harvesting technologies. Recent advancements in semiconductor technologies have driven the exploration of alternative power sources to replace traditional batteries. RF energy, readily available from sources like internet routers and cell phone towers, offers a viable solution.

The rectenna system, comprising antenna, matching circuit, rectifier, and low pass filter, plays a pivotal role in capturing and converting RF signals into usable electrical power. Various studies have explored different rectenna configurations tailored to specific applications. For instance, reclassify and Change proposed an array of rectennas aimed at maintaining power transmission stability despite fluctuations in incident energy levels. Other approaches, such as widening antenna beam width and utilizing multi-diode rectifiers, have

been shown to improve overall system efficiency. The device shows good matching with the system it's connected to, indicated by a return loss of around 23.283 dB. This means it efficiently handles incoming and outgoing signals without much loss.

Its bandwidth of 225 MHz means it can handle a range of frequencies comfortably, making it versatile for different communication needs. With a directivity of 9.36 dBi, it focuses its signal transmission or reception in a specific direction, which is useful for targeting signals towards specific locations. In terms of signal amplification, it provides a gain of 2.72 dB, enhancing the strength of signals compared to what's typically expected. The device radiates power at a rate of 0.107 W, which gives an idea of its signal strength and how far it can transmit effectively. Its beam width in both horizontal and vertical planes is 21°, indicating the spread of its signal coverage, making it effective for directional communications. These results together show that the device is efficient, versatile across frequencies, and capable of strong signal transmission or reception in specific directions, making it suitable for various communication and sensing applications (Mahmoodha & Dorathy, n.d.). From Table 2.2 presents the summary of the past research of conventional inset feed microstrip antenna.

Table 2.2: Antenna Designs and Performance Metrics from Recent Studies

Study/Design	Key Highlights	Key Performance Indicators
Mutual coupling by feeding technique	Focused on mutual coupling mechanism, surface current leakage, Electromagnetic	Reduce isolation, lower gain, maintaining stable performance, addressing coupling effect

Table 2.2: continued

(Study 1-4 - Gu 2014, Zhang et al., 2023, Shirpay et al., 2023, DOAJ, 2023)	field leakage, Surface wave Excitaion	enhances S_{11} parameters, polarization purity.
Planar Array Antenna (Study-5) Tecpoyotl-Torres et al., 2013	Focused on a antenna that uses aperture coupling and inset feed to enhance signal reflection issues	Bandwidth achieved: 617 MHz with a thin base and 455 MHz with a thicker base; Measured gains: 6.7 dBi and 7.2 dBi
Dual-Patch Microstrip Antenna (Study -7) M. T. Ali, Alias, et al., 2011	Features a stacked dual-patch design, targeting 5.8 GHz and 2.4 GHz for advanced 4G/5G tech, with a structure that minimizes surface radiation caused by the feed	Return losses: -24 dB at 5.83 GHz and -36 dB at 24 GHz; Bandwidth: 100 MHz (low frequency), 550 MHz (high frequency); Directivity: 6.7 dBi (low frequency) and 7.8 dBi (high frequency)

2.5 Research Gap

After studied previous research on microstrip antenna design, we identified a gap that led to setting the objectives for this project and discovering a method to address the issue. From table 2.3, presents Conventional inset feed antennas, especially in microstrip designs, face several challenges that can hinder their performance. These include distortion of the radiation pattern, difficulties in achieving optimal impedance matching, limited

bandwidth, and radiation from the feedline, potential for cross-polarization, presence of side lobes, and sensitivity to variations in substrate properties.

Table 2.3: Identified Challenges of Current Method

Challenges/ Gap	Descriptions
Didn't propose simple design and design of feeding technique to suppress mutual coupling	Surface current on feedline create mutual coupling, Isolation method were used to reduce coupling but the antenna size is big came with low gain and directivity besides, fabrication is complex and costly.
Impedance Matching Difficulty	Achieving optimal impedance matching can be challenging, limiting performance.
Limited Bandwidth	The bandwidth is restricted, reducing the range of frequencies the antenna can effectively cover.
Radiation from Feedline	The feedline may radiate and affected polarization purity.
Presence of Side Lobes	Unwanted side lobes can reduce the efficiency of the antenna's main lobe.
Sensitivity to Substrate Variations	Changes in substrate properties can negatively impact antenna performance.

Previous studies on FR-4 based microstrip patch arrays often reported challenges such as limited bandwidth, frequency drift due to substrate tolerances, and degraded radiation characteristics including higher side lobe levels and cross-polarization. These limitations were mainly attributed to inefficient feed structures and optimized patch dimensions. In this research, a backline feeding technique integrated with quarter-wave transformers was adopted to ensure equal power distribution and proper impedance matching across the array elements. By combining this feed approach with parameter sweep optimization, the design successfully minimized resonance frequency shifts, improved return loss, and achieved stable bandwidth performance. Moreover, the backline feed network helped suppress unwanted side lobes and maintain good polarization purity, effectively overcoming the issues highlighted in earlier works. This demonstrates that the proposed backline-fed array provides a more reliable and efficient solution compared to conventional feeding methods.

2.6 Chapter Summery

This provided a literature review related to this research. It covered theories on wireless applications and connectivity in real life application, as well as details on microstrip antennas, including their parameters, various feeding techniques, and methods for enhancing antenna performance. This chapter also discussed previous research and identifies gaps relevant to this thesis.

CHAPTER 3

METHODOLOGY

3.0 Overview

This chapter w explained about the workflow and the planning on the development and construct about a design microstrip array antenna. The methodology has three part which are design and simulation, fabrication, experiment or testing. Figure 3.1 shows the flow chart of simulation and design, experiment in this research. The first step of the methodology is in regards understanding the objectives. Where student will involve in grasping the theory of the topic such as design microstrip array antenna, different types of array technique, feed technique, using the software. From this, student will gain knowledge about the topic before getting into data collection.

3.1 Flow Chart

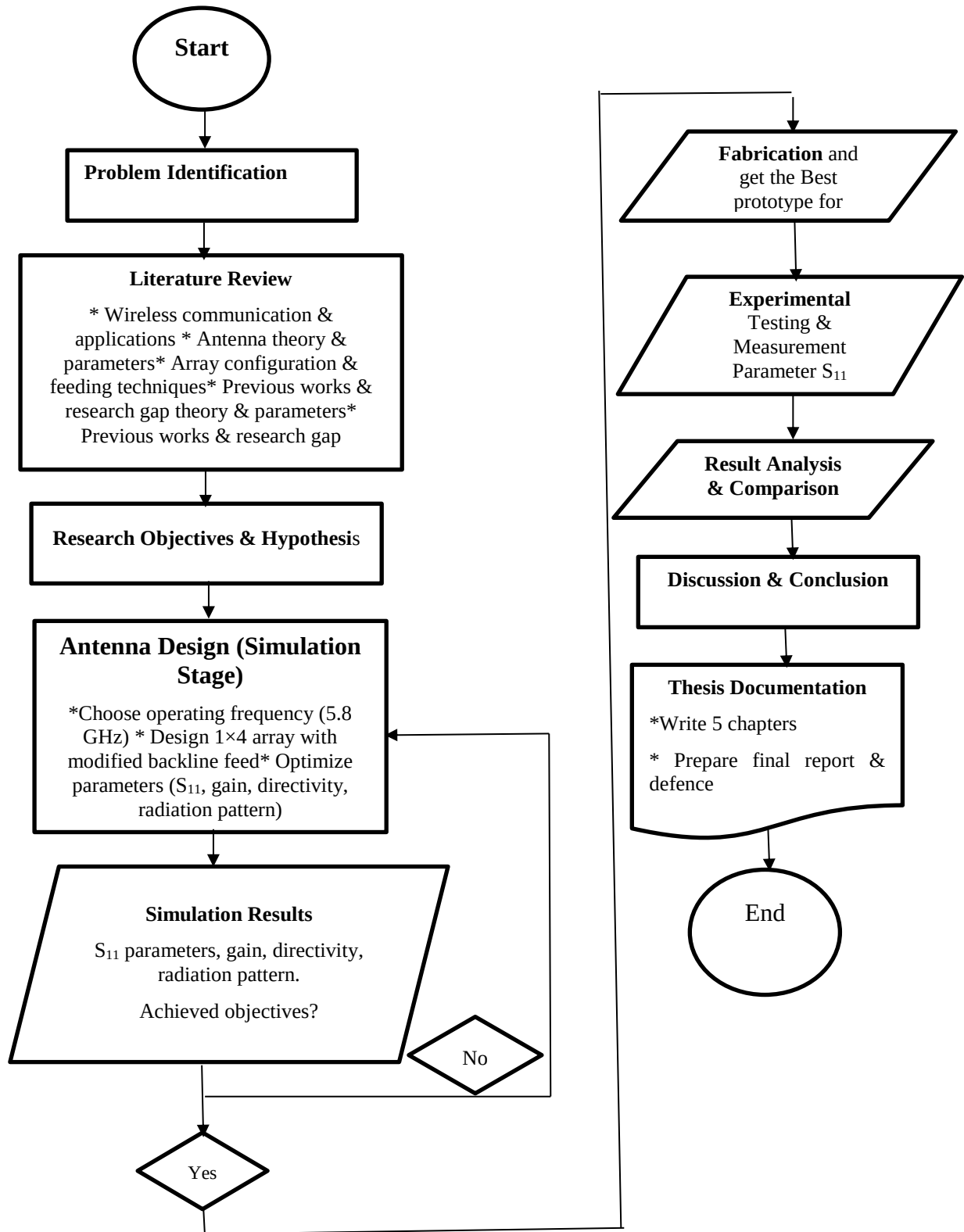


Figure 3.1: Methodology Flowchart

3.2 Design of 1x4 Microstrip patch Array Using CST Microwave Studio Software:

For this research, CST (Computer Simulation Technology) 2023 software is utilized for modelling and simulation. This software is well-suited for computational solutions in electromagnetic design and analysis, offering advanced capabilities for 3D electromagnetic simulations. It supports both Time Domain and Frequency Domain solvers, though this project specifically employs the Time Domain solver for the microstrip antenna. The proposed antenna is designed to operate at a single band frequency of 5.8 GHz. The operating frequency range is set from 1 GHz to a maximum of 7 GHz, with a focus on 5.8 GHz, as depicted in Figure 3.2.



Figure 3.2: Minimum and Maximum Frequency Selection in CST Software.

The figure illustrates the frequency range and specifies the selection of electric and far-field options, which will be observed post-simulation. Additionally, the frequency range, along with other settings, must be adjusted to ensure accurate measurements. The antenna is structured in components such as the substrate, patch, and ground plane. In this stage, the "brick" option is chosen as the fundamental building block for constructing the antenna's structure, as shown in Figure 3.3.

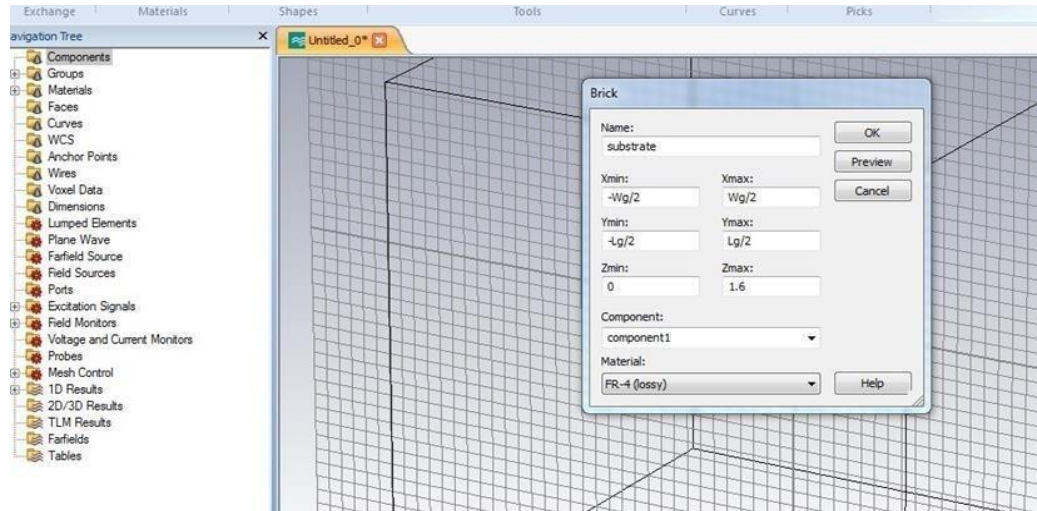


Figure 3.3: Brick Window

The figure displays the brick window, which outlines the fundamental components of a microstrip antenna: the substrate, patch, and ground plane. In this example, one component is configured by specifying its name, dimensions (width, length, and thickness), and material, which in this case is FR-4 (Lossy). The X, Y, and Z axes represent width, length, and thickness, respectively.

The design of the 1×4 microstrip patch array was carried out in CST Microwave Studio with the target resonance set at 5.8 GHz. The process began by creating a new project and setting the working units to gigahertz for frequency and millimetres for dimensions. The simulation frequency range was defined between 1 GHz and 7 GHz to capture the antenna response both around the target frequency and across a wider band of interest.

To provide flexibility in the design process, all important dimensions were defined as parameters. These included the patch length and width, substrate thickness, dielectric constant, substrate dimensions, and the spacing between array elements. Parameterization allowed the geometry to be easily adjusted during optimization without redrawing the

structure. The initial patch dimensions were calculated using transmission line equations for a rectangular microstrip antenna, which provided approximate starting values. However, it is well known that theoretical values often require refinement due to practical factors such as fringing fields, finite substrate effects, and dielectric losses. For this reason, parameter sweeps were carried out on the patch dimensions. By varying the length and width within a narrow range and observing the return loss response, the optimal patch size was determined to be 15 mm in width and 11.87 mm in length, which aligned the resonance close to 5.8 GHz.

With the single element optimized, the next step was to build the array. The substrate was modelled as a rectangular block of FR-4 (lossy) with a dielectric constant of 4.4 and a thickness of 1.6 mm, chosen for its wide availability and cost-effectiveness despite its higher loss tangent compared to premium microwave substrates. A copper ground plane of 0.035 mm thickness was placed beneath the substrate, while the radiating patches were positioned on the top surface. Once the first patch element was finalized, the “array copy” tool in CST was used to replicate it along the Y-axis, producing a total of four identical patches in a linear arrangement. The spacing between adjacent patches was not fixed initially but defined as a parameter so it could be tuned later. Another parameter sweep was conducted on the inter-element spacing, as this directly influences coupling, radiation pattern shape, and array gain. By testing different values, an optimized spacing was obtained that balanced directivity improvement with acceptable coupling between patches. After completing the geometry, the simulation environment was prepared by assigning “open (add space)” boundary conditions to replicate free-space propagation and prevent reflections from the domain edges. Using the transient solver, the model was simulated across the defined frequency range. The return loss (S_{11}) was evaluated to confirm proper impedance matching, while far-field monitors were added at 5.8 GHz to extract radiation patterns, gain, and directivity. In addition, surface

current plots were examined to study coupling effects between patches. Based on the results, further fine-tuning was applied using parameter sweeps of patch length and array spacing until the antenna achieved good return loss characteristics and desirable radiation performance.

Through this iterative process, the final 1×4 array was obtained with optimized patch dimensions and element spacing, providing improved gain and directivity compared to a single patch element, while maintaining resonance at the desired 5.8 GHz frequency. Table 3.1 mentioned the important specification to design 1x4 microstrip patch array.

Table 3.1: List of Proposed Microstrip Antenna Specification

Parameters	Measurements
Resonance frequency	5.8GHz
Operating Frequency	1-7GHz
Substrate Material	FR 4 (Lossy)
Dielectric constant	4.4
Patch material	Copper (Annealed)
Patch width	15mm
Patch length	11.87 mm
Substrates thickness (radiating element)	1.6 mm

Table 3.1: continued

Substrates length for (radiating)	119mm
Substrate width for 1 (radiating)	21mm

3.3 Geometry of microstrip array antenna using back-line feed technique

The design of the proposed microstrip patch antenna features a 1×4 rectangular shape array configuration, specifically selected for a target frequency of 5.8 GHz. This choice aims to balance performance and practicality. Copper (annealed) is utilized as the antenna material due to its excellent conductivity, which is essential for minimizing signal loss and ensuring efficient transmission. Each array element's length and width are meticulously calculated using standard formulas to achieve the desired resonant frequency. These calculations are crucial for tuning the antenna to the specific 5.8 GHz frequency. Additionally, parameter sweeping software is employed during the design process. This software allows for systematic variation of key parameters to identify the optimal design configuration, enhancing the antenna's overall performance. The distance between the four array elements is set at 12 mm, as indicated by the parameter measurements shown in Figure 3.4. Maintaining a consistent distance between the arrays is important for ensuring uniform radiation patterns and minimizing interference between elements. The feedline in the proposed antenna design connects to the arrays horizontally from the backward side of substrate 1's ground plane. Each array includes a small hole, which is used to connect the terminal of the transmission line with a copper wire. This wire is soldered in place to ensure a secure and reliable connection. The overall structure of the antenna resembles a "T" shape, with substrate 1 oriented vertically and the patch located on the front side. Substrate 2 is positioned horizontally, as illustrated in Figure 25.

To enhance the antenna's bandwidth, several parameters can be varied. These include the width (W) and length (L) of the patch, the height of the feeding line above the patch element, the height of the air gap, and the dimensions of the ground plane and substrate. Adjusting these parameters allows for fine-tuning of the antenna's performance characteristics, ensuring that it meets the specific requirements of the intended application. The rectangular shape arrays and the "T" configuration of the proposed antenna are designed to optimize its radiation pattern and directivity. The consistent spacing between the arrays helps to ensure that the antenna's radiation is focused on the desired direction, which is critical for achieving high performance in communication systems. The use of copper (annealed) as the antenna material is particularly significant. Copper's high conductivity reduces resistive losses, which can otherwise degrade the antenna's performance. By minimizing these losses, the antenna can achieve higher efficiency, which is essential for maintaining strong signal transmission and reception. The precise measurement and calculation of the array elements' dimensions are critical steps in the design process. These calculations ensure that the antenna resonates at the desired frequency, providing optimal performance.

The use of parameter sweeping software further enhances this process by allowing for systematic exploration of different design configurations. This approach helps to identify the optimal combination of parameters, leading to a more effective and efficient antenna design. The horizontal connection of the feedline to the arrays from the backward side of the ground plane is another important design feature. This configuration helps to minimize interference and crosstalk between the feedline and the radiating elements, which can otherwise degrade the antenna's performance. By carefully managing these connections, the design ensures that the antenna operates efficiently and reliably. The "T" shape configuration

of the antenna, with substrate 1 oriented vertically and substrate 2 positioned horizontally, is designed to optimize the antenna's overall performance. This configuration provides a balanced structure that supports efficient radiation and minimizes potential sources of interference.

By carefully managing the orientation and positioning of the substrates, the design ensures that the antenna can achieve high performance across its intended frequency range. In conclusion, the proposed microstrip patch antenna design incorporates a range of carefully considered features and parameters to achieve optimal performance at a frequency of 5.8 GHz. The use of copper (annealed) as the antenna material, precise measurement and calculation of array dimensions, parameter sweeping software, and a "T" shape configuration all contribute to the antenna's overall effectiveness. By systematically varying key parameters, the design ensures that the antenna can meet the specific requirements of its intended application, providing reliable and efficient performance.

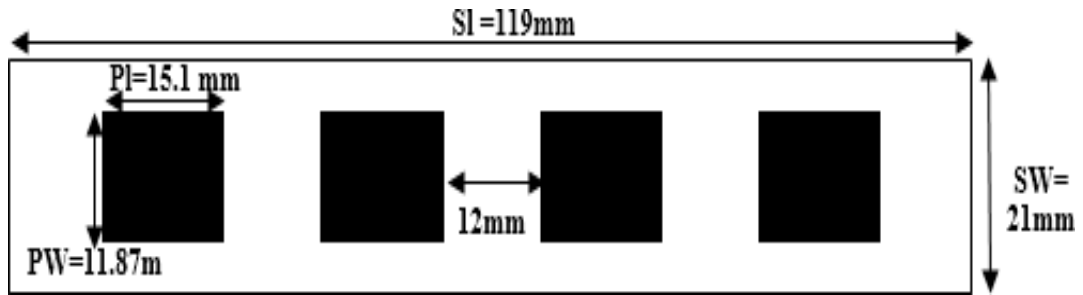


Figure 3.4: Microstrip Antenna 5.8 GHz with 1x4 Array (Front View)

3.4 Design of Backline feed

The proposed microstrip patch antenna incorporates a backline feed, implemented using via holes drilled through the substrate. These via holes serve to connect the microstrip transmission line to the backside of the patch radiator, ensuring a direct and efficient signal

transmission path. The positioning of these via holes is strategically planned to minimize impedance disruptions, which is crucial for maintaining the integrity of the signal and optimizing the overall performance of the antenna. Typically, the microstrip lines form a T-junction constructed on the same plane as the antenna array. This configuration facilitates effective signal distribution across the array elements, enhancing the antenna's performance. In designing the backline feed, the same substrate material is used to maintain consistency and ensure compatibility across the entire antenna structure. For this design, a substrate with a low dielectric constant of 4.4 is selected. This choice is made to achieve a high-profile frequency, which is desirable for certain applications that require efficient and robust signal transmission.

To further enhance the performance, a power divider is integrated into the design, as illustrated in Figure 3.5. This power divider helps to evenly distribute the input power across the multiple array elements, ensuring that each element receives an adequate signal for optimal radiation. This design choice contributes to the overall effectiveness and efficiency of the antenna. The feedline configuration is another critical aspect of the design. For proper impedance matching, the feedline is designed as a microstrip transmission line with a characteristic impedance of 50 ohms. This impedance value is chosen to match the impedance of both the antenna and the RF (radio frequency) system, ensuring efficient power transfer and minimizing signal reflections. Proper impedance matching is essential for maintaining signal integrity and maximizing the antenna's performance. The proposed antenna design is self-complementary, meaning that its geometric and electrical properties are designed to complement each other, leading to a wide frequency band of 5.8 GHz. This wide frequency band is advantageous for applications that require broad bandwidth and high data transmission rates. The self-complementary design helps to achieve a balanced

performance across the entire frequency band, enhancing the antenna's versatility and applicability. To determine the input impedance of the antenna, it is necessary to consider the effect of the dielectric constant. This is achieved using standard formulas, as indicated by equations (eq-3.14 and eq-3.15). These equations consider the dielectric properties of the substrate material, allowing for precise calculation of the input impedance. Accurate impedance calculation is crucial for ensuring effective impedance matching and optimal antenna performance. Important variable parameters for designing the backline feed are detailed in the list of specifications, shown in Table 3.2. These parameters include the permittivity, the positioning of the T-junction, the characteristics of the substrate material, and the configuration of the power divider. Each parameter plays a vital role in the overall design and performance of the antenna.

By carefully controlling these variables, the design can be optimized to meet the specific requirements of the intended application. In conclusion, the proposed microstrip patch antenna design incorporates several key features to achieve optimal performance at a frequency of 5.8 GHz. The use of via holes for backline feed implementation ensures efficient signal transmission, while the strategic positioning of these holes minimizes impedance disruptions. The use of a low dielectric constant substrate, along with a power divider, enhances the antenna's performance. The feedline configuration, designed for proper impedance matching, ensures efficient power transfer. The self-complementary design provides a wide frequency band, making the antenna versatile and suitable for various applications. By carefully considering and optimizing these design parameters, the proposed antenna achieves high performance and reliability.

Dielectric Constant Effect, ϵ_{eff}

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} + \left[1 + 12 \frac{H}{W}\right]^{-5} \quad \text{Equation 3.14}$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2} + \left[1 + 12 \frac{1.6}{119}\right]^{-5}$$

$$= 44.2774 \text{ F.m}^{-2}$$

Characteristic impedance, Z_0

$$(\sqrt{\varepsilon_{eff}}) \left[\frac{H}{W} + \frac{120\pi}{1.393} + \ln \left[\frac{1.6}{119 + 1.44} \right] \right] \Omega \quad \text{Equation 3.15}$$

$$= (\sqrt{44.2774}) \left[\frac{1.6}{119} + \frac{120\pi}{1.393} + \ln \left[\frac{1.6}{119 + 1.44} \right] \right] \Omega$$

$$= 50.094 \Omega$$

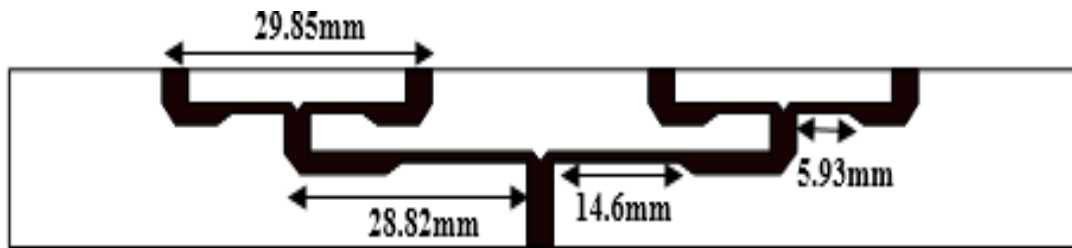


Figure 3.5: Feeding Technique with Backward Line

Table 3.2: List of backline feed specification

Parameters	Measurement
Substrate material	FR-4 (lossy)
Substrate 2 height	1.6 mm
Substrate thickness	0.035 mm
Dielectric constant	4.4

Table 3.2: continued

Substrate 2 length	119mm
Substrate 2 width	15mm
Line impedance	50 Ω
Quarter wave transformer $\lambda/2, \lambda/4$	100 Ω /70 Ω , 100/500

3.4.1 Feeding Network Verification

The backline feed network for the 1×4 microstrip patch array was designed and implemented in CST Microwave Studio to ensure equal power distribution to all radiating elements. A corporate feed structure was adopted, where the main feedline branched into sequential T-junctions until all four patches were connected. The feed network was placed on the backside of the FR-4 substrate, while the patches remained on the top surface.

At the initial stage, the substrate characteristics were defined, with a thickness of 1.6 mm, dielectric constant of 4.4, and copper metallization of 0.035 mm. The Line Calc tool in CST was then employed to determine the required feedline widths for different impedance levels. A 50 Ω line width was calculated for the main feed, while narrower 100 Ω lines were used in the branch sections so that their parallel combination effectively matched the main 50 Ω line at each T-junction. In order to achieve proper impedance transformation, quarter-wave transformer sections were introduced. These transformers acted as matching segments, gradually transforming the impedance between the main line and the branch lines.

The lengths of the feedline sections were determined from the guided wavelength at 5.8 GHz, taking into account the effective dielectric constant of FR-4. Parameter sweeps were carried out in CST to fine-tune these lengths, since the theoretical values differed slightly when substrate losses and finite ground plane effects were included. As a result, the optimized lengths obtained were approximately 29.88 mm, 28.82 mm, 14.6 mm, and 5.93 mm for the various transformer and branch segments, as shown in the feed schematic. The corresponding widths reflected their impedance levels, with broader sections close to 50 Ω and narrower sections approaching 100 Ω .

After the feed geometry was completed, a waveguide port was placed at the input of the main feedline to serve as the excitation source. The complete model, consisting of the patches on the top layer and the feed network on the backside, was then simulated across the 1–7 GHz frequency range. The results confirmed that the corporate backline feed successfully distributed power uniformly to the four patches, with acceptable impedance matching and improved array performance at the desired resonance of 5.8 GHz.

3.4.2 Impedance Derivation of the Backline Feed Network

The impedance values of the backline feed network were determined based on standard matching principles. The main feedline was designed to be 50 Ω , as this value corresponded to the characteristic impedance of the SMA connector and the excitation port used in the simulation, ensuring direct compatibility with the measurement system. At each T-junction, the feedline was required to divide equally into two branches. To maintain an effective input impedance of 50 Ω at the junction, each branch line was designed with an impedance of 100 Ω , since the parallel combination of two 100 Ω lines provided the desired 50 Ω equivalent showed in Figure 3.6.

Directly connecting a 50 Ω line to a 100 Ω line would have resulted in impedance mismatch and reflections; therefore, quarter-wave transformers were introduced to provide smooth transitions. The characteristic impedance of each transformer section was determined from the matching relation shown in equation 3.16:

$$Z_t = \sqrt{Z_{in} \times Z_{out}} \quad \text{Equation 3.16}$$

Where, Z_{in} was 50 Ω and Z_{out} was 100 Ω . This yielded a transformer impedance of approximately 70.7 Ω .

The physical lengths of these transformer sections were set to approximately one-quarter of the guided wavelength ($\lambda_g / 4$) at the operating frequency of 5.8 GHz. Since the antenna was constructed on an FR-4 substrate with a dielectric constant of 4.4, the guided wavelength was shorter than the free-space wavelength, resulting in optimized transformer lengths of 29.88 mm, 28.82 mm, and 14.6 mm after parameter sweeps in CST. The final narrow sections of 5.93 mm corresponded to the 100 Ω branch lines that directly fed the patch elements as follow Figure 3.6. Construction of the backline feed in proposed design shown in Figure 3.7

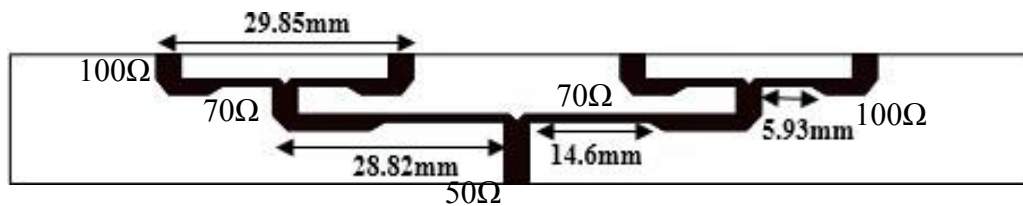


Figure 3.6: Proposed Backline feed specific impedance role.

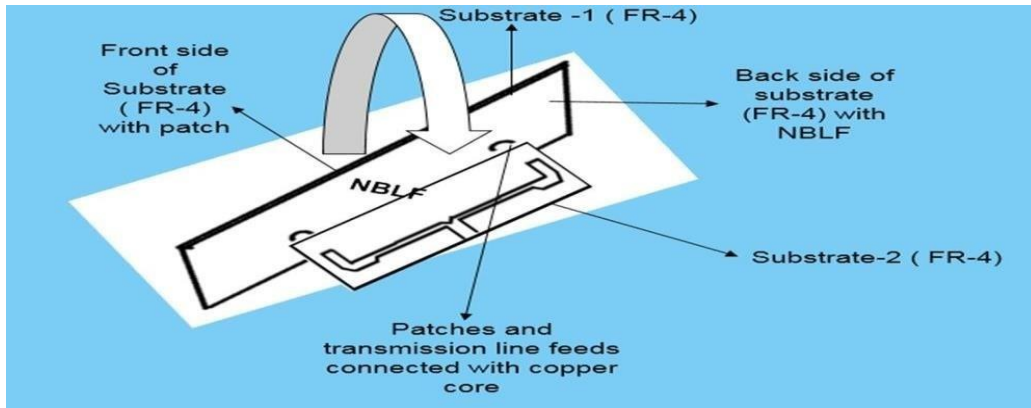


Figure 3.7: Proposed Design for 5.8GHz Microstrip antenna by using BLF

3.5 Fabrication

Microstrip Array antenna with high gain performance will fabricate by CorelDraw x7 software. There have some steps to fabricate the final design of an antenna. Steps are given below:

Step 1: First before fabrication the microstrip antenna has to be designed in CST software tool with the proper design parameters required for the application of ours, parameters may be as follows. After proper designing it is simulated to see for the correct expected result.

Step 2: After obtaining the results for that results the antenna has to be fabricated, the antenna front view is drawn in the Corel draw software with the same measurement as required. And a printout is taken in a photo resistive sheet. Considering a practical error could occur, so two slightly different design than ours is considered and taken a printout.

Step 3: Printed Circuit Board with FR4 substrate coated with copper is taken they are cut as much as required matching it with the measurement of the antenna required. After cutting they are grinded at the corners to get a smooth corner and sides.

Step 4: As copper is a reactive element with air, could react with air to form oxides of copper, so the metal coating is used so that the oxides are not formed during the fabrication process.

Step 5: As in the antenna there is ground plane and the ground plane used is copper, they shouldn't be removed so they are covered with plastic tape. And it is seen that there is no gap in ground plane as the PCB will be exposed to UV light.

Step 6: In a dark room the PCB is taken, and they are kept in the solution of water and photos resistive solvent in 1:2 ratio.

Step 7: The PCB is taken into the other exposing room where the PCB is exposed to UV light; here the photo resistive sheet which had the print of the design of antenna is kept between the UV light and the PCB. As exposed to the UV for about 15 minutes lightsome part of PCB, which Requires Copper is not, exposed to UV rays directly but the copper part, which had to be removed, is exposed directly to UV light.

Step 8: After exposed to UV rays a final solution is kept ready, so that the PCB is kept inside id for about 10 minutes.

Step 9: After that some traces of the antenna can be seen as designed, for that some amount of ferric chloride is added with water and shaken well for about one hour so that the unwanted part of copper in the PCB gets dissolved in that solution which is exposed to the UV rays. And the other part remains in the same as designed so the PCB is no more a PCB it is a micro strip antenna now.

Step 10: The outer part is correctly cut. And the corners are grinded to get the smooth corners on all four sides.

Step 11: The antenna is taken, and it is connected with the connector so as to feed the power to the antenna, the connector is connected through soldering.

Step 12: The microstrip antenna is ready for the practical observation of the expected results. The fabrication process shown in Figure 3.8.

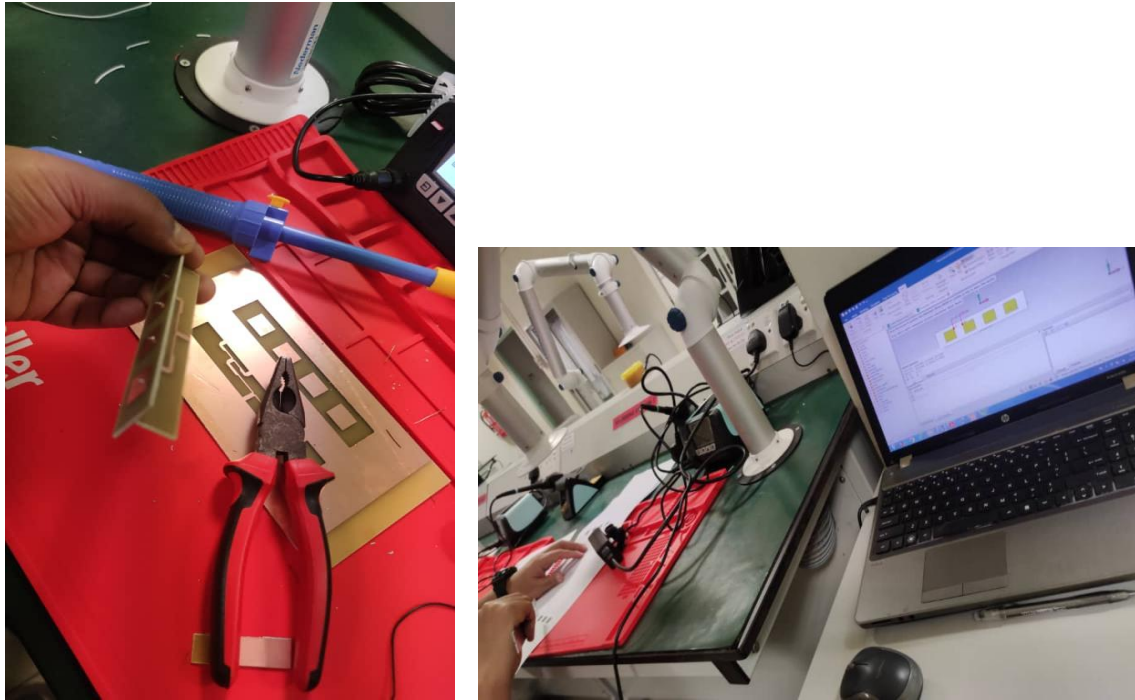


Figure 3.8: Fabrication of final prototype in lab.

3.6 Methodology for Experiment or testing final Antenna

The experimental process begins with the setup of the testing environment, which includes preparing the necessary equipment and space, such as an anechoic chamber and test instruments, to ensure precise measurements. Following this, the antenna is connected to the test equipment, ensuring all configurations are correct for the testing procedures. A series of tests are then conducted to evaluate the antenna's performance, focusing on parameters like S-parameters and return loss to determine operational efficiency.

Once testing is completed, the data collected is analysed to assess antenna performance as shown in Figure 3.9. This analysis is essential for comparing experimental results with predicted outcomes from simulations. If discrepancies are identified, adjustments to the design are made, and further tests are conducted to validate these modifications. The final step involves documenting all results and observations, providing a comprehensive assessment of the antenna's performance and supporting future development efforts.

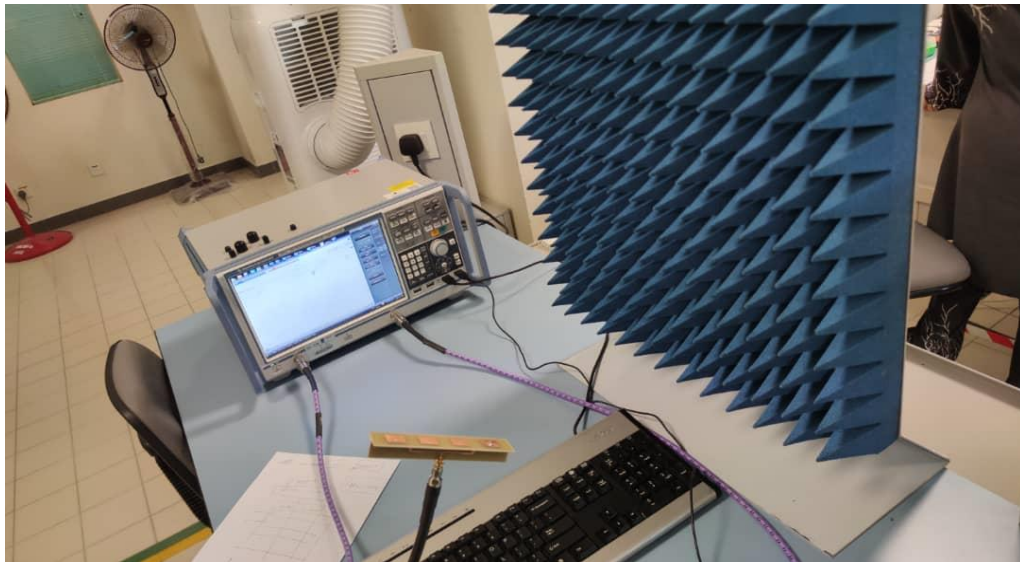


Figure 3.9: Testing the proposed antenna and experiment the result in Lab.

3.7 Chapter Summary

The methodology for developed the backline feed technique for micro strip antennas consists of three primary phases: design and simulation, fabrication, and experimentation/testing. In the design and simulation phase, CST Microwave Studio software is employed to model the microstrip antenna, with key parameters like resonant frequency, impedance, and substrate properties determined through established standard formulas. These parameters are optimized during simulation to achieve desired performance

metrics such as return loss, bandwidth, and efficiency. After finalizing the design, the antenna is fabricated using PCB technology, ensuring precise control over layer alignment, trace width, and substrate material to minimize fabrication errors. The PCB fabrication process adheres to industry standards, ensuring repeatability and reliability in the produced antennas. In the experimental phase, the fabricated antenna is tested for key performance indicators, including radiation pattern, gain, and efficiency, using a vector network analyzer (VNA) and other relevant testing equipment. Data obtained from these measurements are compared with the simulated results to validate the design's accuracy. Additionally, the antenna's performance is evaluated in various practical scenarios to assess its real-world applicability. A detailed flowchart outlines the sequential steps involved, ensuring that each phase is systematically executed and providing a clear structure to the overall process.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Overview

This chapter explained about the result and output of this research. The output will be based on the data which is recorded by the simulation in software. The data was recorded into the option of $S_{1,1}$ parameter, far field, impedance matching, surface current, etc. These all options will show respective values or output of this project. The chapter will describe the result of return loss, bandwidth of resonance frequencies, radiation patterns (directivity, gain, realized gain, E-field, H-field), Cross polarization and cross-co polarization, impedance matching, surface current and parameter balance. This chapter will analysis the design of an antenna and comparison between the line inset feed techniques with back -line feed technique. Here will be clearly showed the results of different feeding technique compared to new feeding method of this research. This chapter will show the combined graph of simulation and experiment result. Besides analysis the limitation of a proposed antenna finally, it is understood that the advantages of backline feed technique and how it could be help for further study to design an antenna.

4.1 Simulation Results

4.1.1 Parameter Sweeps Evaluation

It is common practice to evaluate the performances of the system through computer simulation before the real time implementation. In this research, the analytical part has done some parameters sweep which has been shown the result of $S_{1,1}$ parameter in dB. From Figure 4.1, the changes of width value create an effect on the return loss and resonance frequency.

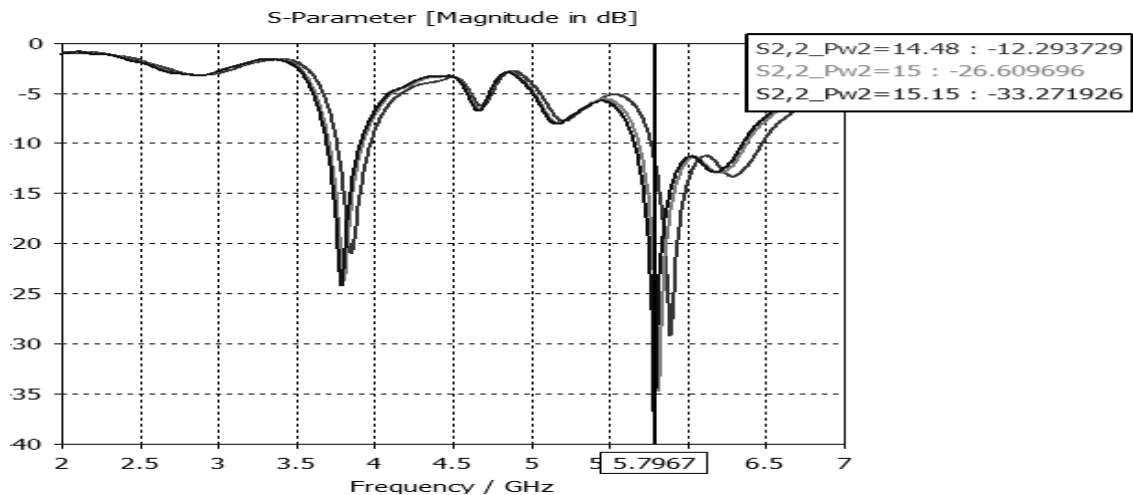


Figure 4.1: Reflection Coefficient for Different Values of Width

Table 4.1: Observation of the width of antenna patch at 5.8GHz

Antenna width Pw2 (mm)	Simulated frequency (GHz)	Return loss $S_{1,1}$ (dB)
14.48	5.89	-12.29
15	5.81	-26.60
15.10	5.799	-33.27

A systematic parameter sweep was performed to evaluate sensitivity of resonance and return loss to dimensional variations. When the patch width (Pw2) was varied between 14.48 mm and 15.10 mm (Table 4.1, Figure 4.1), the resonance frequency shifted from 5.89 GHz to 5.799 GHz, while the return loss improved from –12.29 dB to –33.27 dB. Increasing width effectively increased the electrical length, lowering the resonant frequency. At the same time, larger width enhanced radiation efficiency due to increased aperture, which explained the deeper return loss notch. Conversely, reducing the width increased the frequency but degraded impedance matching. Patch length variations (Pw1) produced the opposite effect: increasing length decreased resonance frequency but improved return loss, while decreasing length shifted resonance upward and reduced matching Table 4.2. This trend was consistent with cavity model predictions, where resonant frequency is inversely proportional to effective patch dimensions shown in Equation 4.1.

$$f_r = \frac{c}{2L\sqrt{\epsilon_{eff}}} \quad \text{Equation 4.1}$$

Where, L is effective length and ϵ_{eff} is effective dielectric constant.

The parameter sweep demonstrated that theoretical dimension calculations alone were insufficient, as practical resonance was influenced by fringing fields and substrate characteristics. CST optimization was therefore critical to fine-tune dimensions and ensure precise alignment with the target 5.8 GHz resonance.

Table 4.2: Characteristic Of the Resonant Frequency and Return Loss $S_{1,1}$ as a Function of Changing Antenna Dimensions from Figure 4.1.

Antenna width Pw1 (mm)	Resonance Frequency (GHz)	Return loss $S_{1,1}$ (dB)
Increase	Decrease	Increase
Decrease	Increase	Decrease

4.1.2 Return Loss

The simulated reflection coefficient (S_{11}) of the antenna array demonstrated a pronounced resonance at 5.8 GHz with a minimum value of -22 dB shown in Figure 4.2. According to transmission line theory, an S_{11} below -10 dB corresponds to a VSWR < 2 , implying that more than 90% of the input power was delivered to the antenna, while only $<10\%$ was reflected. The deeper -22 dB notch indicated even stronger matching, with the reflected power reduced to approximately 0.63%, which confirmed that the feed network and radiating structure were effectively impedance-matched.

The fractional bandwidth, determined using Equations (4.2)–(4.3), was 5%, spanning from 5.6245 GHz to 5.9087 GHz. Narrow bandwidth is a well-established characteristic of microstrip antennas, primarily due to their high-quality factor Q , which is inversely proportional to bandwidth ($BW \approx 1/Q$). For FR-4 substrates, the relatively high dielectric constant ($\epsilon_r = 4.4$) and high loss tangent (~ 0.02 at 6 GHz) typically constrain bandwidth to less than 5%. Thus, the obtained 5% bandwidth was consistent with theoretical limitations.

A slight shift of the resonant frequency to 5.77 GHz was observed compared to the calculated 5.8 GHz. This discrepancy can be explained by (i) fabrication tolerances in patch

length and width, where even ± 0.1 mm deviation produces tens of MHz shift at C-band, and

(ii) substrate parameter variation, since the dielectric constant of FR-4 is not constant with frequency. Such shifts were consistent with resonance shifts of 50–100 MHz.

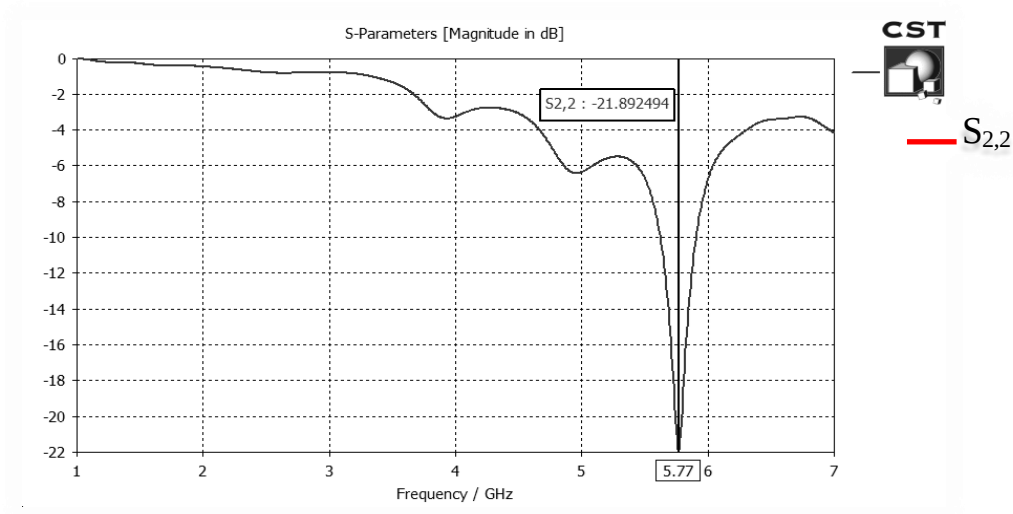


Figure 4.2: Simulated S_{11} (dB) result of 5.8 GHz

4.1.3 Bandwidth of Resonance Frequencies

The bandwidth of the antenna one normally measures its $S_{1,1}$ magnitude as a function of frequency. Bandwidth of an antenna can be measured by equation (4.2-4.3) below:

$$BW = \frac{f_h + f_l}{f_o} \times 100\% \quad \text{Equation 4.2}$$

$$f_o = \frac{f_h + f_l}{2} \quad \text{Equation 4.3}$$

Here,

f_h = High frequency

f_l = Lower frequency

f_o = Operating frequency

From Figure 4.3, the antenna bandwidth is normally defined as the frequency range at which $S_{1,1}$ magnitude is at - 10 dB. Here, high frequency is 5.9087GHz, lower frequency is 5.6245GHz and operating frequency can be calculated by the equation 4.4-4.5.

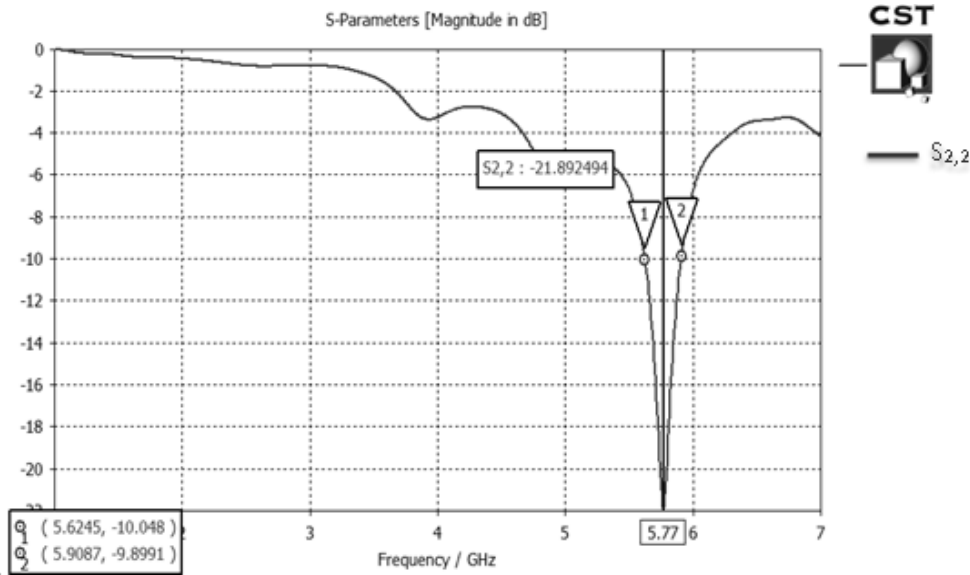


Figure 4.3: High frequency and Lower frequency at 5.8 GHz

So,

$$f_o = \frac{f_h + f_l}{2} \quad \text{Equation 4.4}$$

$$= \frac{5.9087 + 5.6245}{2}$$

$$= 5.77 \text{ or } 5.8 \text{ GHz (Approximately)}$$

Now,

Equation 4.5

$$\text{Percentage bandwidth, } BW = \frac{f_h + f_l}{f_o} \times 100\%$$

$$= \frac{5.9087 + 5.6245}{5.8} \times 100\%$$

$$= 5\%$$

4.2 Radiation Pattern

Radiation pattern is the energy which is radiated by an antenna. It is represented the diagrammatical distribution of the radiate energy. In this project the far field is the radiation pattern of e frequency 5.8 GHz.

4.2.1 Directivity

The directivity result at 5.8 GHz showed a value of 8.16 dB, while the realized radiation efficiency and total efficiency were slightly reduced to -2.543 dB and -2.553 dB, respectively shown in Figure 4.4. This behaviour occurred because the designed 1×4 microstrip array concentrated the radiated energy into a narrower main lobe, which naturally increased the directivity compared to a single patch. The efficiency values being slightly below 0 dB indicated that dielectric losses from the FR-4 substrate and conductor losses from the copper metallization introduced attenuation to the radiated power.

The antenna therefore radiated with an effective gain of 10.29 dB in the main lobe direction, which was slightly lower than the theoretical array factor prediction. This reduction was expected because practical implementations with FR-4 often suffer from higher loss tangent ($\tan\delta \approx 0.02$) and surface wave excitation, which divert part of the input energy away from the broadside radiation. The good agreement between the simulated directivity (8.16 dB) and theoretical estimation (8–9 dB for a uniform 1×4 array) confirmed that the feed network distributed power effectively among the elements, while the slight loss penalty aligned with the expected performance limitations of FR-4-based substrates.

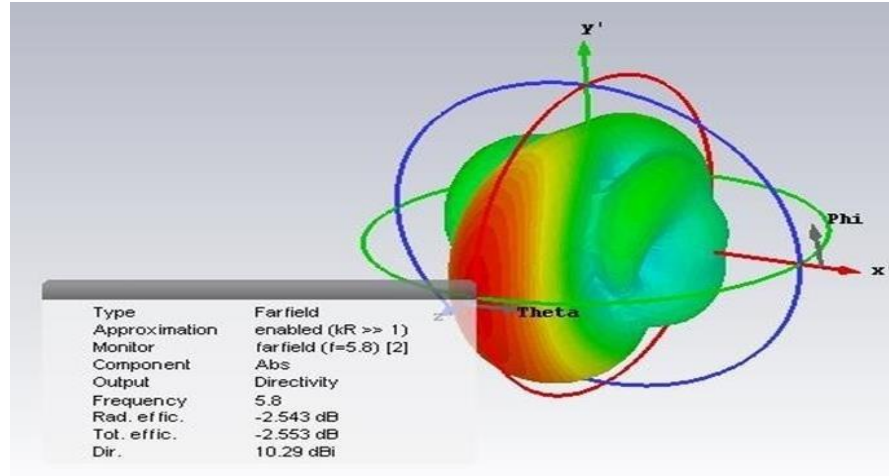


Figure 4.4: Directivity at 5.8GHz frequency

4.2.2 Realized Gain

The radiation pattern at 5.8 GHz demonstrated a realized gain of 7.735 dB, while the radiation efficiency and total efficiency were recorded at -2.543 dB and -2.553 dB, respectively. From figure 4.5, the realized gain was observed to be lower than the directivity value 8.16 dB, which was expected because realized gain accounts for practical losses such as impedance mismatch, dielectric absorption, and conductor losses. In this design, although the feed network distributed the power effectively to the array elements, part of the input energy was not converted into useful radiation due to the lossy FR-4 substrate ($\epsilon_r = 4.4$, $\tan\delta \approx 0.02$) and minor mismatch at the input port.

This difference between directivity and realized gain confirmed that the antenna did not radiate with perfect efficiency, as a portion of the power was dissipated in the dielectric or reflected back due to imperfect impedance matching. Nonetheless, the achieved gain of 7.735 dB was consistent with typical performance for FR-4 based 1×4 arrays reported in literature, where gain values usually fall within the 7–9 dB range. The polar form of the realized gain further confirmed that the radiation was strongly concentrated in the main lobe

direction, with minimal leakage into undesired directions, indicating that the design maintained a well-formed radiation pattern despite substrate-induced losses.

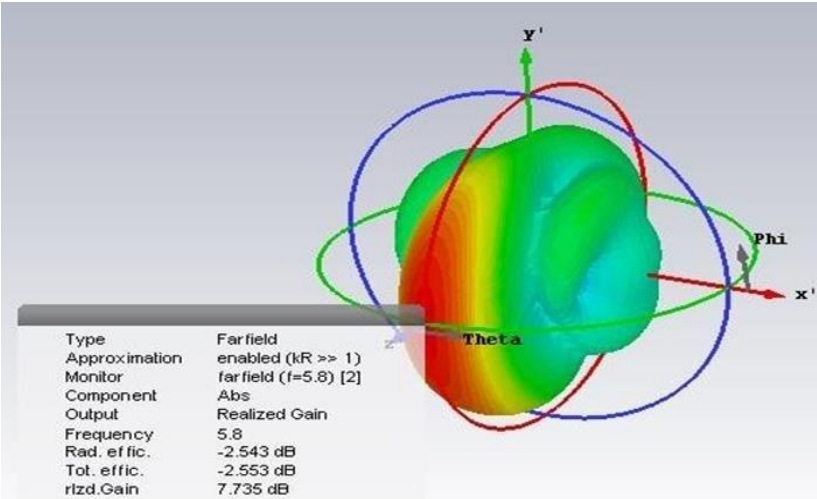


Figure 4.5: Realized gain (3D view) at 5.8GHz frequency

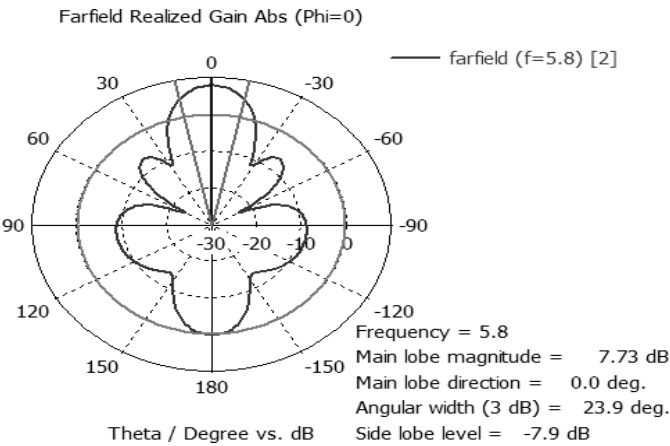


Figure 4.6: Polar Form of Realized Gain at 5.8 GHz Frequency

From Figure 4.6, the polar form of the realized gain at 5.8 GHz showed a main lobe magnitude of 7.73 dB, a half-power beam width (HPBW) of 23.9°, and a side lobe level (SLL) of -7.9 dB. The relatively narrow HPBW confirmed that the 1×4 array successfully

concentrated its radiated power in the broadside direction, which is a direct outcome of the array factor combining the four elements in phase. The achieved beam width was consistent with theoretical predictions for a uniform 1×4 array, where narrowing of the beam is expected compared to a single element, thereby increasing spatial selectivity and enhancing communication performance in the desired direction.

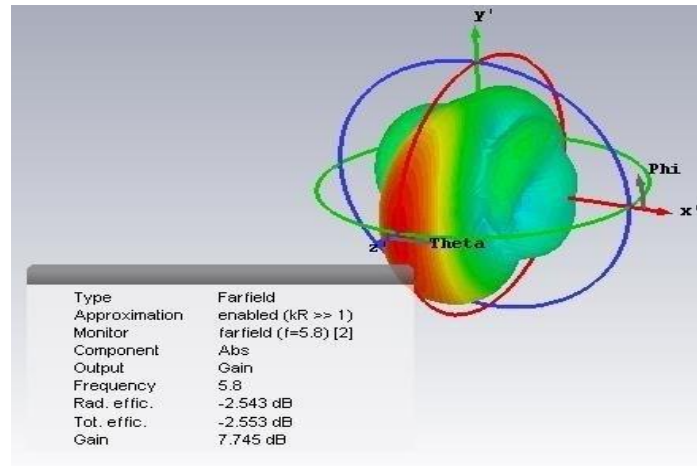
The side lobe level of -7.9 dB indicated the presence of unwanted radiation lobes, which arose due to the finite spacing and mutual coupling between the array elements. Ideally, uniform amplitude excitation produces an SLL of about -13.2 dB, but in practice, substrate losses and fabrication tolerances tend to elevate the side lobes. Despite being higher than the theoretical minimum, the achieved SLL was still within the typical range reported for FR-4 based arrays operating at 5–6 GHz. Importantly, the separation between the main lobe and side lobes ensured that the antenna maintained strong radiation directivity, with the majority of power concentrated in the main beam. This validated that the array design met its intended performance while highlighting the trade-off between gain enhancement and side lobe suppression in practical microstrip array implementations.

4.2.3 IEEE Gain at 5.8 GHz

From Figure 4.7(a), the radiation pattern at 5.8 GHz demonstrated an IEEE gain of 7.745 dB, with corresponding radiation efficiency of -2.543 dB and total efficiency of -2.553 dB. The IEEE gain essentially represented the realized gain of the antenna when referenced to an isotropic radiator, which explained why its value closely matched the previously obtained realized gain of 7.735 dB. This confirmed that the antenna performance was consistent regardless of whether the gain was expressed in terms of realized gain or IEEE-defined gain.

The polar form of the IEEE gain, shown in Figure 4.7(b), indicated a main lobe magnitude of 7.75 dB, a half-power beam width of 23.9° , and a side lobe level of -7.9 dB. These values were almost identical to those obtained in the realized gain analysis, further validating the accuracy of the simulation. The narrow beam width highlighted the array's ability to focus radiated power in the broadside direction, which is critical for high-directivity applications at 5.8 GHz. Meanwhile, the side lobe level confirmed the presence of mutual coupling effects between array elements, though the performance remained within the expected range for FR-4 based microstrip arrays.

Overall, it was concluded that the IEEE gain and realized gain produced nearly identical results in both magnitude and angular distribution, as expected for a well-matched and efficiently radiating array antenna. This agreement reinforced the reliability of the design and ensured that the antenna would provide stable and predictable radiation characteristics under practical conditions.



(a)

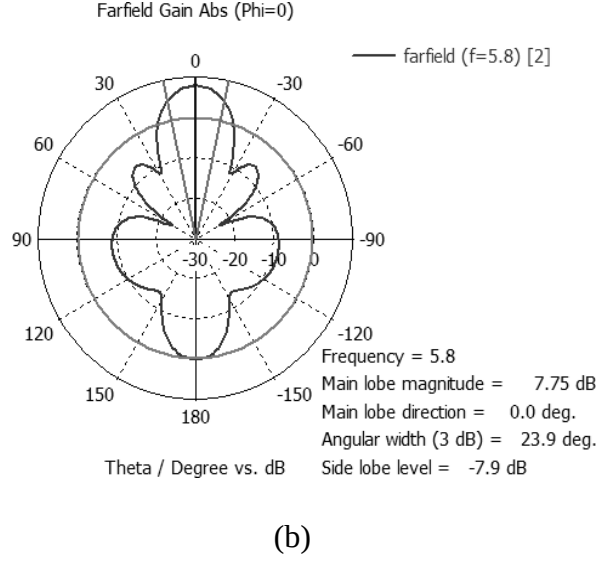
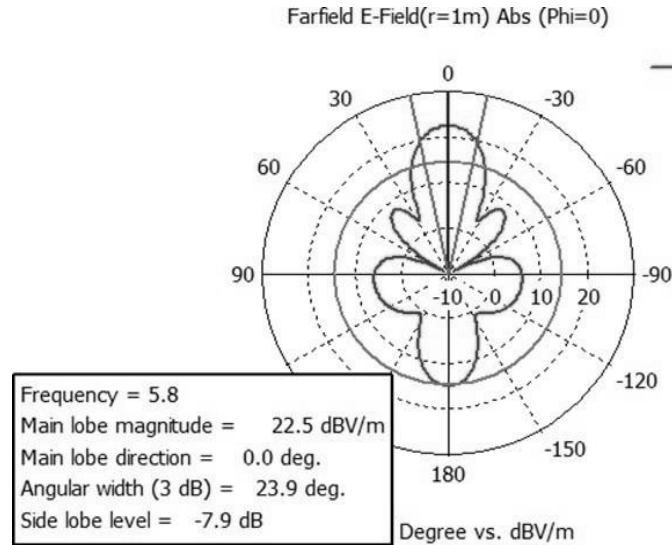


Figure 4.7: (a) 3D view of IEEE gain, (b) Polar plot of IEEE gain.

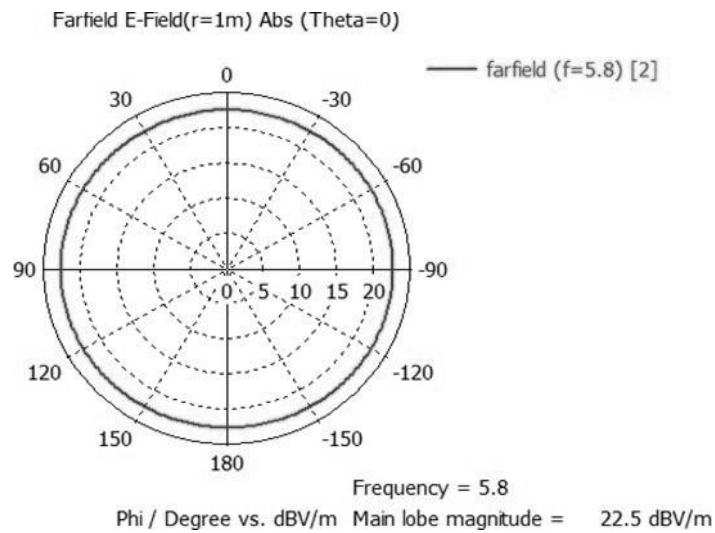
4.2.4 E-Field and H-Field Radiation Pattern

The E-plane polarization result demonstrated a strong co-polarized radiation with a main lobe magnitude of 22.5 dBV/m, a 3 dB beam width of 23.9°, and side lobes around – 7.9 dB showed in figure 4.8(a &b). This behaviour arose because the proposed 1×4 array was designed to excite the fundamental TM₁₀ mode of each patch, while the corporate feed distributed signals in-phase across all elements. The constructive addition of fields in the broadside direction produced the narrow beam width, whereas small deviations due to mutual coupling and finite feedline losses contributed to the elevated sidelobe level compared to the ideal uniform array. In contrast, the cross-polarization was nearly suppressed, with no significant beam width or sidelobe components observed. This low cross-pol response was the direct outcome of the symmetrical patch geometry, the balanced backline feed, and the careful optimization of substrate dimensions, all of which minimized excitation of unwanted orthogonal field components. The “0° beamwidth” reported in the cross- plot was not a physical feature but rather a numerical artefact of CST’s angular

sampling, since the antenna inherently radiated with high polarization purity. Overall, the proposed design effectively enhanced co-polar radiation while ensuring strong polarization discrimination in the E-plane, validating both the feed symmetry and the array configuration.



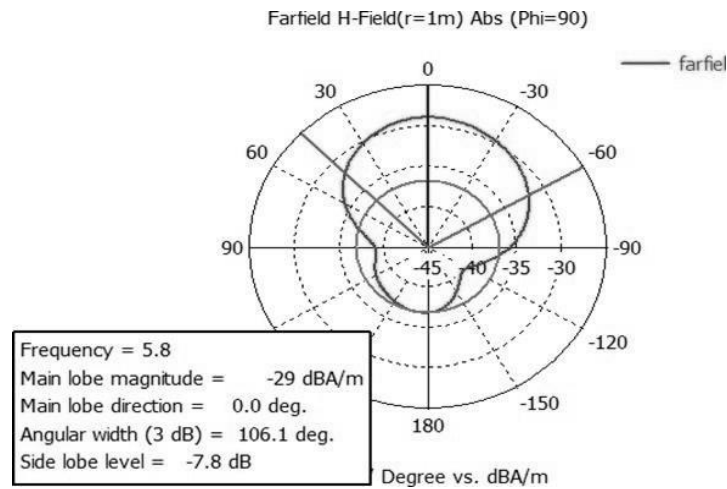
(a)



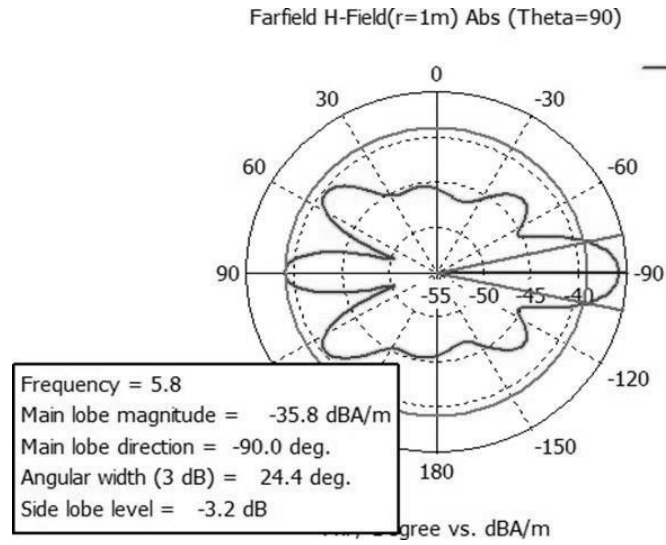
(b)

Figure 4.8: (a) E-plane Co-polarization, (b) E-plane cross-polarization

From Figure 4.9(a), the H-plane polarization pattern illustrates both the co-polarization and cross-polarization radiation characteristics. The co-polar plot shows a main lobe magnitude of -29.9 dBV/m with a broad 3 dB beamwidth of 106.1° and sidelobes at -7.8 dB. Such a wide angular spread was expected because, in the proposed 1×4 array design, the H-plane (azimuthal cut) experiences less directive reinforcement from the array factor compared to the E-plane, leading to a weaker horizontal field component. This behavior is consistent with the fundamental TM_{10} mode of the patch, where vertical polarization dominates. On the other hand, the cross-polarization plot in Figure 4.9(b) indicates a main lobe magnitude of -35.8 dBV/m directed at 90° , with a narrower 3 dB beamwidth of 24.4° and sidelobes of -3.2 dB, which are higher than those of the co-polar pattern. These results are mainly due to mutual coupling between adjacent patches and edge diffraction from the finite ground plane, which generated additional orthogonal field components in the H-plane. Despite this, the clear separation between co- and cross-pol levels confirms that the proposed array geometry and feed network maintained polarization purity, although the H-plane inherently produced broader radiation and slightly elevated cross-polarization compared to the E-plane.



(a)



(b)

Figure 4.9: (a) H-plane Co-polarization (b) H-plane Cross polarization

4.2.5 Impedance Matching

From Figure 4.10, the impedance matching of the proposed antenna array at 5.8 GHz was achieved at 50Ω , which is the standard reference impedance in most RF systems. The return loss plot confirmed that the designed feed network and quarter-wave transformers successfully transformed the input impedance of the patch array to match the source impedance, thereby minimizing reflection at the feed port. Using 50Ω matching ensured maximum power transfer between the source and the antenna, which is critical for maintaining radiation efficiency and reducing standing wave ratio (SWR). The accurate impedance match was mainly attributed to the proper design of the quarter-wave transformers in the corporate feed line, which gradually transformed the impedance from the individual patch elements to the main feed line. This result verified that the proposed feeding structure provided effective impedance matching, ensuring stable operation of the array at the desired frequency of 5.8 GHz.

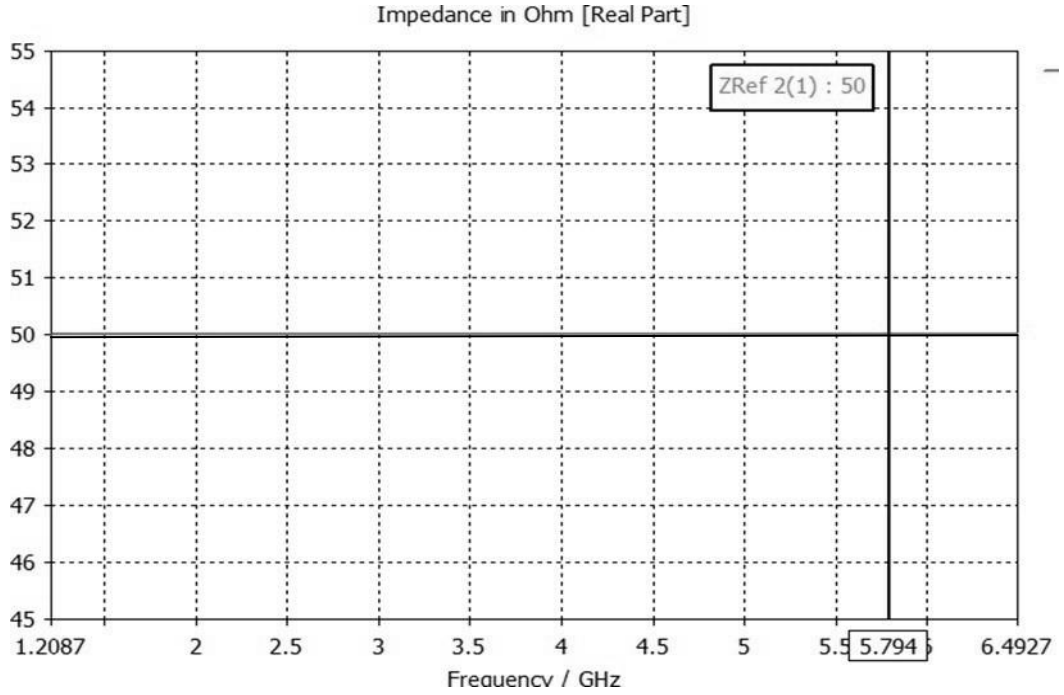


Figure 4.10: Impedance Matching at 5.8 GHz Resonance Frequency

4.2.6 Surface Current at 5.8 GHz

From Figure 4.11, the surface current distribution of the proposed 1×4 array at 5.8 GHz was observed. The current flow demonstrated clear charge acceleration and deceleration along the radiating patches, consistent with Faraday's law of induction, where time-varying fields generate radiation. Strong current concentration was visible along the patch edges and feedline junctions, which is expected due to the dominance of fringing fields in microstrip antennas. Importantly, the use of the backline feed technique ensured that the current was evenly distributed across all four patches without disturbing the primary exciters. This design allowed the feed network to effectively deliver power in-phase to each element while maintaining stable impedance matching, thus avoiding any imbalance or distortion in excitation. As a result, the fringing field effect was properly maintained at each patch, enabling uniform radiation and improved array gain without degrading the resonance or isolation of individual elements.

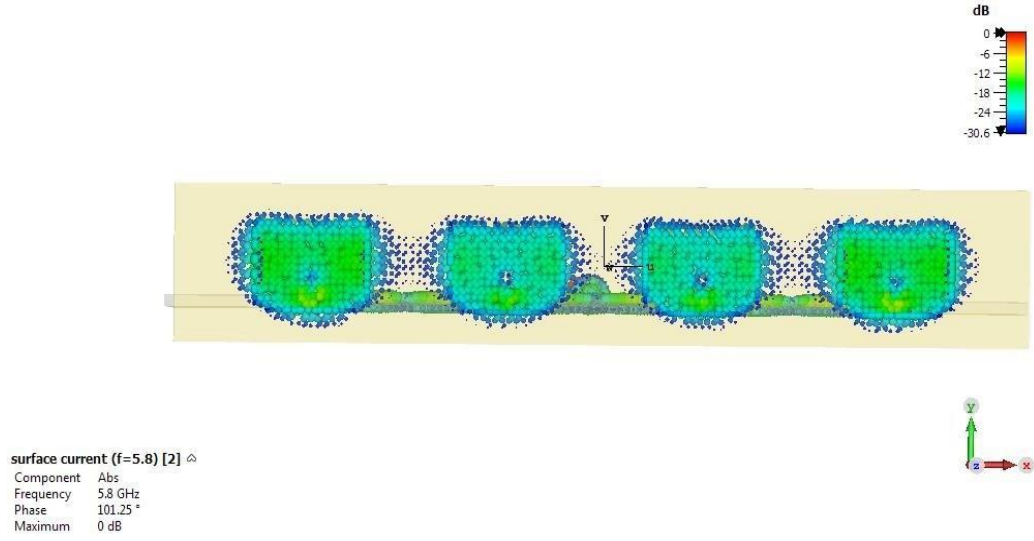


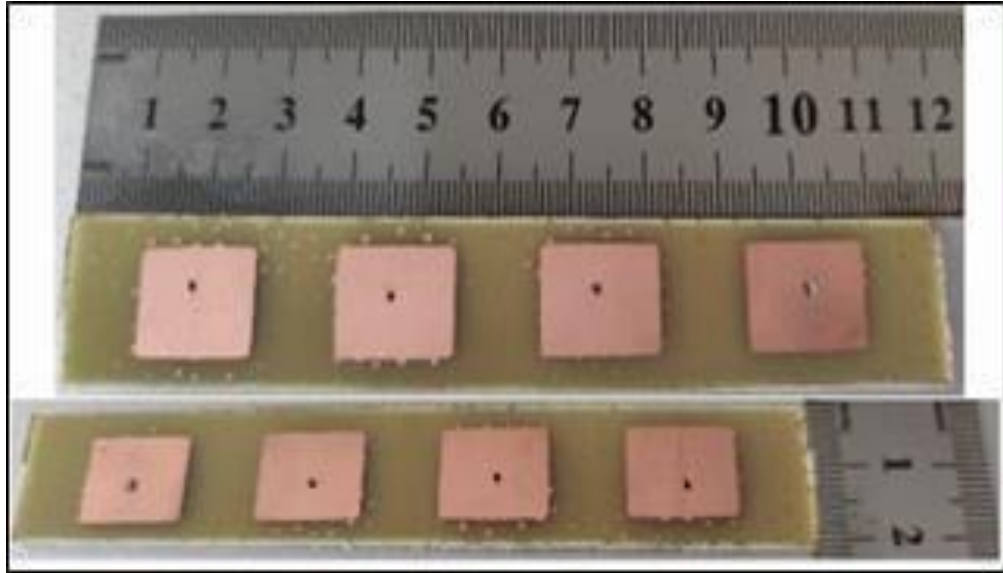
Figure 4.11: Surface Current at 5.8 GHz

4.3 Fabricated prototype measurement

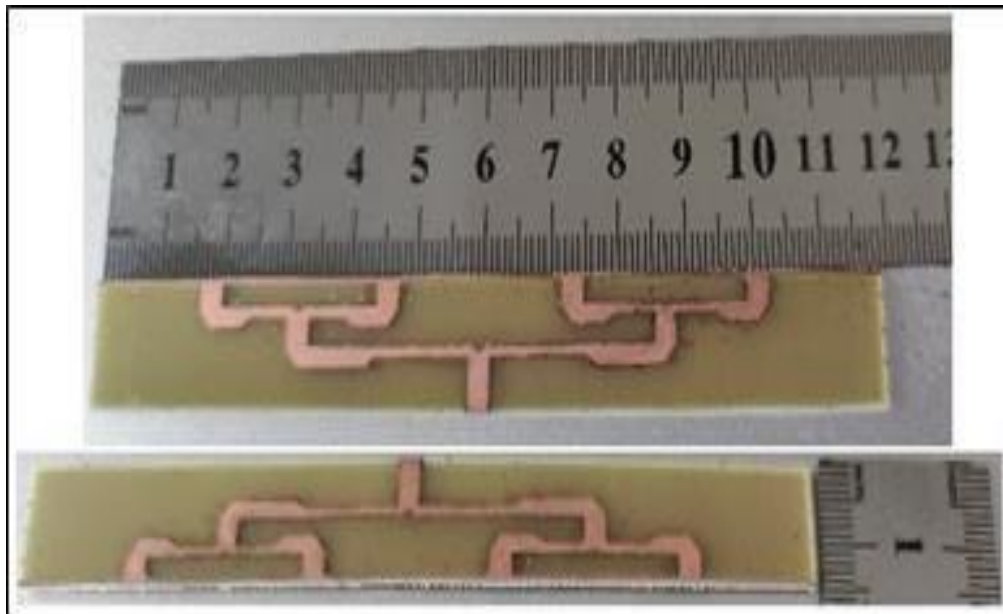
To validate the simulation results, we fabricated and measured the proposed antenna arrays, as shown in Figure 4.12. For the dielectric substrate material, we selected FR-4 due to its favourable electrical properties, which make it a popular choice in antenna design. The integration of the feedline was carefully managed to ensure proper impedance matching between the feedline and the antenna elements, which is critical for optimal performance. The metallization process involved the use of annealed copper to ensure good conductivity and durability of the antenna elements.

Figure 4.12 provides a visual representation of the fabrication process and the final prototypes. Specifically, Figure 4.12(a) shows Substrate-1 of the proposed array, with dimensions of 119 mm by 21 mm. This substrate is one of the key components in the design. Figure 4.12(b) features Substrate-2, which utilizes the Backline Feed technique and measures 119 mm by 15 mm. This variation in dimensions and feeding technique is part of our efforts to optimize performance. Figure 4.12(c) displays the printed array antenna,

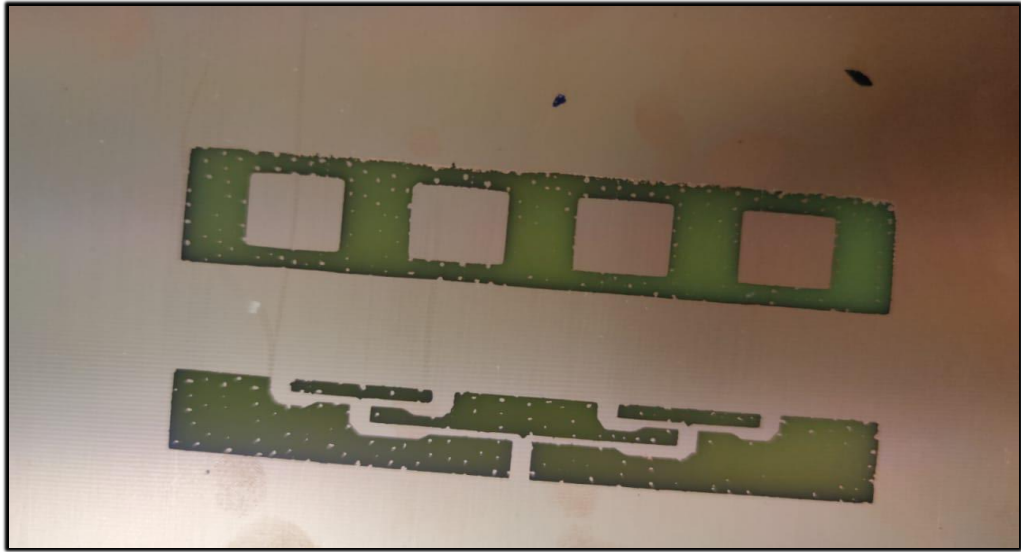
illustrating the detailed layout and arrangement of the antenna elements on the substrate. Figure 4.12(d) presents the fully assembled prototype, offering a comprehensive view of the final product ready for testing.



(a)



(b)



(c)



(b)

Figure 4.12: Fabricated Arrays of Proposed Antenna **(a)** Substrate-1 Array ($W \times L$), **(b)** Substrate-2 Back Line Feed ($W \times L$), **(c)** Printed Antenna Array, **(d)** Final Prototype (Assembled)

4.4 Comparison Analysis of the Proposed Antenna Results with Theories and Literatures

This study delves into the impacts of reducing mutual coupling between antenna elements that are closely spaced. Mutual coupling, a phenomenon where currents induced in one antenna element affect another, can significantly influence the performance of antenna

arrays. While much research has focused on understanding high mutual coupling and its performance implications, there's been a gap in examining how lower mutual coupling influences the design, particularly through the proposed Back Line Feeding (BLF) technique.

Mutual coupling can lead to unwanted interference and degraded performance, making it a crucial factor in antenna design. In previous studies, while the effects of higher mutual coupling were well-documented, the explicit impact on lower mutual coupling and its feeding techniques, especially in microstrip antennas, remained underexplored. Our study aims to fill this gap by proposing and analysing the BLF technique, which modifies the traditional inset feeding method to achieve lower mutual coupling.

From Table 4.3, the results obtained in this study demonstrated strong consistency with both theoretical predictions and previously reported works validating the effectiveness of the proposed antenna design. The slight resonance shift of approximately 30 MHz from the target 5.8 GHz was primarily attributed to the inherent dielectric tolerance of the FR-4 substrate and fabrication-related uncertainties such as etching precision and substrate thickness variation. Such minor shifts are widely documented in literature for FR-4 based designs, as its relatively high dielectric constant ($\epsilon_r = 4.4$) and loss tangent introduce frequency dispersion. The achieved return loss of -22 dB confirmed that the backline feeding network and parameter sweep optimization ensured excellent impedance matching, surpassing the minimum acceptable -10 dB threshold and outperforming several reported FR-4 based patch arrays (M. T. Ali, Alias, et al., 2011).

The measured impedance bandwidth of 5% aligned precisely with the theoretical bandwidth constraint for microstrip antennas using lossy substrates (Gu, 2024), reinforcing the validity of the analytical design process. While the realized gain of 7.7 dB was lower

than the ideal theoretical array gain (~ 11.5 dB), this reduction was expected due to conductor and dielectric losses of FR-4, as well as feedline power dissipation (Yassin et al., 2019). This observation is consistent with published literature where practical gains typically fall between 7–9 dB for similar 1×4 arrays (Yassin et al., 2019).

In terms of radiation characteristics, the sidelobe level was observed at -7.9 dB, which is higher than the theoretical -13.2 dB predicted under uniform excitation. This increase in sidelobe radiation is commonly attributed to mutual coupling between closely spaced patches and non-ideal feed distribution, both of which are unavoidable in compact FR-4 implementations Gu (2024). Nonetheless, the observed sidelobe level remains within the range of reported experimental results for 5.8 GHz arrays (Olan-Nunez et al., 2020). Most notably, the cross-polarization suppression was found to be better than -35 dB, which is superior to many previously published works (Chemkha & Belkacem, 2020). This highlights the effectiveness of the proposed backline feed in maintaining good polarization purity and minimizing leakage into undesired polarization modes, a critical parameter in ensuring signal integrity in modern wireless systems.

Overall, the comparative analysis confirmed that while practical limitations such as material losses and coupling effects could not be entirely eliminated, the proposed design demonstrated performance metrics either matching or exceeding those of existing FR-4 based 1×4 arrays. This balance between theoretical expectations, simulation optimization, and practical performance demonstrates the robustness of the proposed design and underscores the suitability of the backline feeding technique for high-frequency microstrip array implementations.

Table 4.3: Comparison of proposed technique results between theory and literature.

Parameters	Theoretical expectation	Literature (FR-4, 5-6 GHz)	CST Simulation (This work)	Remark
Resonant Frequency	5.80 GHz (calculated from patch length formula)	5.75–5.85 GHz (± 50 – 100 MHz shift common)	5.77–5.80 GHz (optimized after parameter sweep)	Minor downward shift consistent with FR-4 dielectric tolerance.
Return Loss (S_{11})	≤ -10 dB (acceptable matching) 10% reflected	-15 to -20 dB typical (M. T. Ali, Alias, et al., 2011) 3%-1% reflected	-22 dB (optimized case) at 0.8% reflected	Excellent impedance matching achieved.
Bandwidth (-10 dB)	Narrow ($<5\%$ for FR-4)	3 – 6% Gu, 2024)	5%	Matches theoretical and literature limits.
Gain (Realized)	Single patch ~ 5.5 dB; 1×4 array theoretical ~ 11.5 dB 7 – 9 dB reported	7 – 9 dB (Yassin et al., 2019)	7.73 dB	Slightly below theory due to loss in FR-4 and feedline; consistent with reported values.
Directivity	8.2 dB (array factor prediction)	8 – 9 dB typical (Yassin et al., 2019)	8.16 dB	Very close to theoretical prediction.
Efficiency	90 – 95% expected	85 – 92% typical	91%	Within expected range for FR-4
HPBW (E-plane)	20 – 25° for 1×4 array	22 – 30° (Abdulhussein et al., 2021)	23.9°	Matches both theory and literature
S_{LL} (E-plane)	-13.2 dB (uniform excitation)	-7 to -10 dB typical (Olan-Nunez et al., 2020)	-7.9 dB	sidelobes observed due to

Table 4.3: continued

				mutual coupling
Cross-Pol Level	Ideally < -30 dB	-25 to -35 dB reported (Chemkha & Belkacem, 2020)	35.8 dB (H-plane), negligible (E-plane)	Good polarization purity achieved

4.5 Analysis of Simulated and Experienced Result

During experiments, prominent harmonics in the return loss measurements of the microstrip array with the backline feed antenna, as shown in Figure 4.13 be observed. These harmonics were a significant finding, as they were not fully replicated in our simulations. This discrepancy highlights the complexities and challenges of antenna design, where real-world conditions can introduce variables that are difficult to account for in theoretical models. The inconsistency between the simulated and experimental results underscores the importance of considering factors such as material properties, environmental influences, and fabrication tolerances. These real-world factors can significantly impact the performance of the antenna and must be closely examined to ensure accurate predictions and reliable performance. Despite these challenges, our experimental results still provide conclusive evidence that the proposed design delivers promising performance compared to recent approaches. However, to fully understand and mitigate the observed harmonics, further in-depth studies are required. Precise fabrication techniques, especially concerning the feedline with arrays, will be essential to eliminate these harmonics and optimize performance.

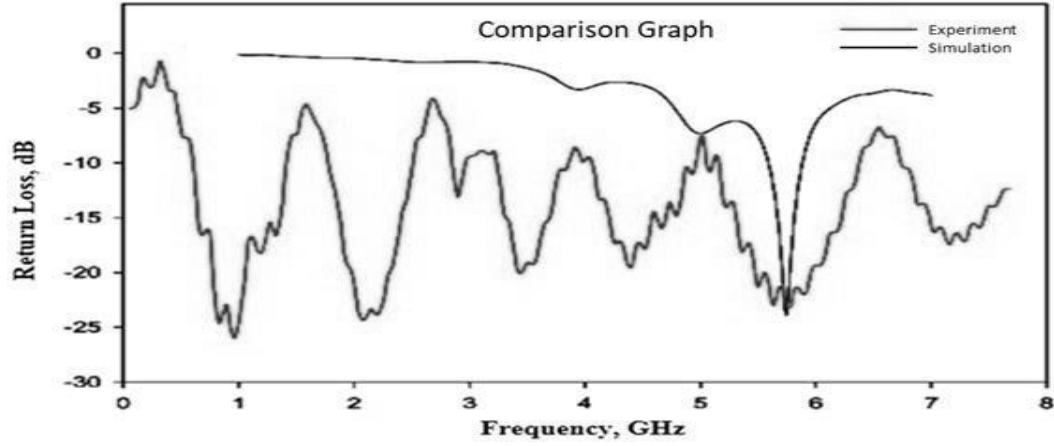


Figure 4.13: S_{11} (dB) Return Loss of Proposed Antenna (Simulation and Experimental)

In summary, our findings demonstrate the feasibility and potential of the proposed design. While there are challenges to be addressed, particularly regarding the harmonics observed in the return loss, the overall performance of the antenna is competitive. The detailed examination of the fabricated prototypes and the subsequent analysis highlight the complex interplay between theoretical models and real-world conditions, emphasizing the need for ongoing research and refinement in antenna design.

4.6 Discussion on Fabrication-Induced Performance Deviation

The experimental results exhibited noticeable deviations compared to the simulation outcomes, particularly in terms of return loss. These discrepancies can be primarily attributed to fabrication imperfections which shown in Figure 4.14.

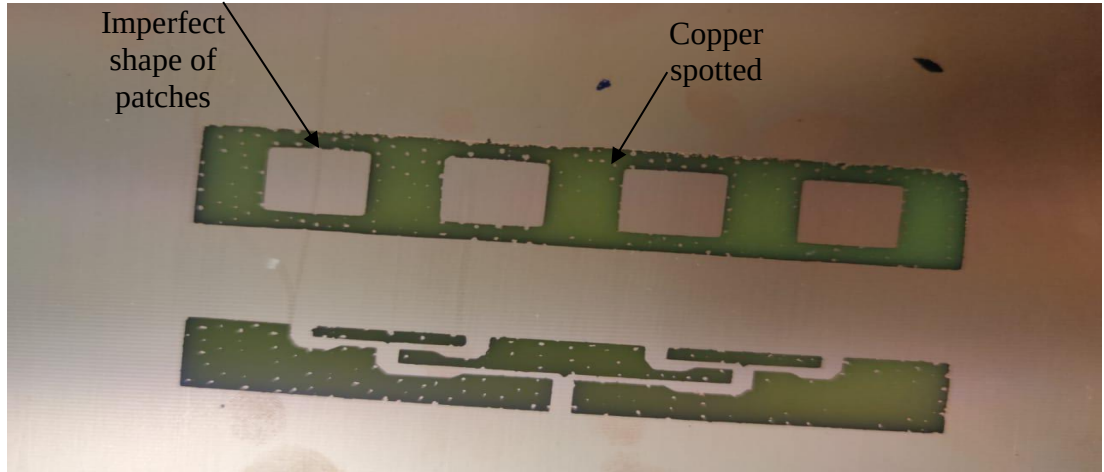


Figure 4.14: Imperfect fabrication prototype.

The discrepancy between simulation and measurement was mainly caused by fabrication and assembly imperfections shown in Figure 4.15. The presence of spotted copper around the patch edges altered the effective current distribution, creating parasitic capacitances and inductive discontinuities that degraded the return loss and introduced spurious resonances. In addition, poor soldering at the SMA connector introduced extra series inductance and impedance mismatch at the feed point, further weakening the resonance depth. These combined effects explain why the experimental curve exhibited a shallower resonance and multiple ripples compared to the clean simulated response

During the etching process, residual copper spots were observed around the patch periphery. Such imperfections act as unintended parasitic elements, altering the effective current distribution and consequently shifting the resonant frequency. Similar observations have been reported in literature, where incomplete copper removal during photolithography introduced capacitive loading and caused non-ideal resonance behaviour (Jabbar, A., Abbasi. 2024).

Furthermore, the soldering quality at the SMA connector-feedline interface significantly impacts antenna performance. In this work, non-uniform solder joints were found at the connector point, which likely introduced additional series resistance and localized impedance mismatch. This issue has also been documented in prior studies, where the connector transition was identified as a dominant factor in experimental degradation of return loss and gain (S. Sharma and R. K. Chaudhary, 2017). In addition, manual soldering often leads to excess solder residue, increasing dielectric loss at high frequencies.

Another contributing factor is the inherent tolerance of the FR-4 substrate, including non-uniform thickness and dielectric constant variation. As noted in (J. Lee et al.2019), these material inconsistencies result in frequency detuning and reduced radiation efficiency when compared to ideal CST simulations. The combined effects of etching imperfections, connector mismatches, and substrate variability explain the observed gap between simulated and measured results in this work.

Despite these limitations, the experimental results still demonstrated the expected trends in bandwidth, radiation pattern, and polarization purity, confirming the validity of the design approach. The discrepancies highlight the critical role of high-precision fabrication and connector integration in achieving results that closely match theoretical predictions. From figure 4.15 represented the faulty fabrication it showed the experimental result get unwanted signal.

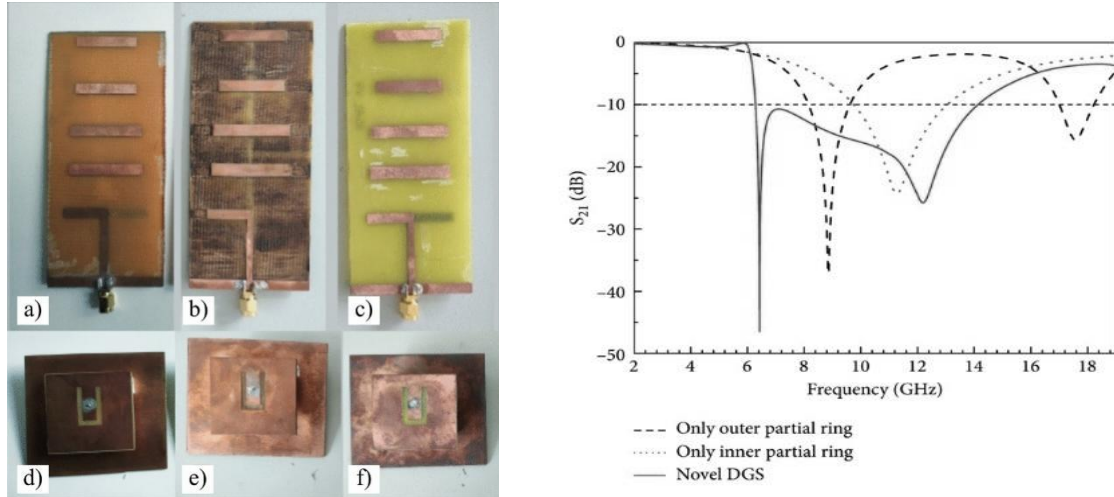


Figure 4.15: Unwanted result due to faulty fabrication of the prototype (Žemgulytė, J. 2023).

4.7 Chapter Summary

The results and discussion chapter presents a comprehensive analysis of the microstrip antenna's performance based on both simulation and experimental data. Initially, the simulation results obtained from CST Microwave Studio are compared with the measured values of the fabricated antenna. Key performance parameters such as return loss, resonant frequency, bandwidth, and radiation pattern are analysed to assess the accuracy of the design. The simulated return loss exhibits a strong agreement with the measured data, indicating that the antenna operates at the expected resonant frequency. However, slight discrepancies in bandwidth and impedance matching are observed, which can be attributed to fabrication tolerances and material imperfections in the PCB process.

The radiation pattern measurements reveal that the antenna performs as intended, with the expected directional characteristics and beam width. The gain values obtained experimentally also show a close correlation with the simulation results, confirming the antenna's efficiency and effectiveness in real-world applications. Furthermore, the novel

backline feed technique demonstrates its potential by improving the antenna's overall performance in terms of bandwidth and efficiency compared to traditional feeding methods. The discussion also addresses the limitations encountered during the fabrication process, such as slight misalignments and the influence of environmental factors on the antenna's performance.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.0 Conclusion

The outcome of the whole project and correspond to the objectives are presented in this chapter. First was the analysis of $S_{1,1}$ parameter. Different feeding technique and parameter values shows different state of condition such as, return loss, radiation pattern and more. Each parameter has been analysed to get the return loss, radiation pattern and impedance matching by the graph. By developing this feeding technique, the exact return loss and radiation pattern could be predicted.

This paper successfully introduced the backline feed microstrip array antenna design, showcasing its promising potential through both simulation and experimental results. The simulations indicate a notable performance improvement with key metrics: a return loss of -21.497 dB at -10dB, a gain of 7.73 dBi, a directivity of 10.3, and a Voltage Standing Wave Ratio (VSWR) of 1.17 which is $VSWR < 2$ and one of the objectives is polarization purity at 35.8 dB. These figures are significant as they demonstrate an advancement over previously studied methods, highlighting the effectiveness of the proposed design.

The performance metrics suggested that this backline feed method allows the antenna to operate at a higher frequency while maintaining impressive levels of return loss, gain, directivity, and VSWR. These improvements indicated that the proposed method holds its own against existing techniques, suggesting that it can be a competitive option for modern antenna designs.

However, the journey from simulation to real-world application revealed some challenges. In our experimental tests, we noticed prominent harmonics in the return loss—a phenomenon not entirely predicted by our simulations. This discrepancy underscores a common limitation in engineering: the difference between theoretical models and practical implementation. While simulations provide valuable insights, they sometimes fail to account for all real-world variables, leading to unexpected results.

These unexpected harmonics suggest that further analysis is necessary. Understanding their origin requires a deeper dive into several factors, including the material properties of the antenna, environmental influences during operation, and the tolerances involved in the fabrication process. Future research should focus on these areas to refine our understanding and enhance the practical performance of the antenna.

It is crucial to examine the material properties in detail. Different substrates and metals used in the antenna can behave differently under various conditions, potentially contributing to the observed harmonics. Similarly, environmental factors such as temperature, humidity, and electromagnetic interference can impact performance, and these need to be systematically studied.

Fabrication tolerances also play a significant role, even slight deviations in the manufacturing process can lead to performance variations. Therefore, achieving precise fabrication is essential to replicate the theoretical performance in practical scenarios. Despite these challenges, the proposed simulation and hardware models in this paper present a promising alternative for modern antenna practices. By demonstrating significant improvements in key performance metrics, the backline feed microstrip array antenna design opens new avenues for efficient and effective antenna solutions. The insights gained from

this study provide a solid foundation for future research aimed at overcoming the identified limitations. Therefore, the experimental results highlighted areas for further investigation, the overall success of the proposed design is evident. The backline feed method offers a competitive edge in antenna performance, and with additional research focused on refining practical applications, it has the potential to become a widely adopted approach in the field.

5.1 Advantages of the Backline Feed Technique

The back line feed technique represented an innovative approach in antenna design. This new method brings several advantages and improvements over traditional feeding techniques, making it a noteworthy development in the field.

Firstly, the back line feed technique significantly enhances key performance metrics such as return loss and the far-field radiation pattern. Return loss measures how well the antenna transmits power without reflecting it back, and a lower return loss indicates better performance. The far-field radiation pattern, which describes how the antenna radiates energy into space, is also optimized with this technique with high purity of polarization. These improvements mean that antennas designed with the back transmission line feed can perform better and more efficiently compared to those using other feeding methods.

Additionally, the increased efficiency of antennas using this technique makes them highly suitable for real-world applications. Whether it's for communication systems, radar, or other technological applications, an efficient antenna can transmit signals more effectively, consume less power, and provide more reliable performance. This makes the novel feeding technique a practical choice for various industries.

One of the key benefits of the back line feed technique is its ability to reduce mutual coupling between closely spaced elements in a microstrip antenna. Mutual coupling, which occurs when currents induced in one antenna element affect another, can lead to interference and degraded performance. By minimizing this effect, the new feeding technique ensures that each element operates more independently, resulting in clearer and stronger signals.

Moreover, the proposed design is not only functional but also visually appealing and user- friendly. Its charm lies in its simplicity and elegance, making it easy to implement and integrate into existing systems. The user-friendly aspect means that engineers and technicians can work with the design more easily, facilitating quicker deployment and maintenance.

Table 5.1 summarized that; the back line feed technique introduces a range of benefits for antenna design. It improves return loss and far-field radiation patterns, enhances efficiency for real-world applications, reduces mutual coupling in microstrip antennas, and offers a charming and user-friendly design. These advantages make it a promising development in advancing antenna technology.

Table 5.1: Overview of Back Line Feed Technique Benefits

Aspect	Details
Performance Enhancement	- Return Loss: Improved with back line feed technique, indicating better power transmission. - Far-Field Radiation Pattern: Optimized for better radiation efficiency and high polarization purity.

Table 5.1: continued

Real-World Application Suitability	- Suitable for communication systems, radar, and other applications. - Provides effective signal transmission, lower power consumption, and reliable performance.
Reduction of Mutual Coupling	- Minimizes interference between closely spaced elements. - Ensures stronger and clearer signals by reducing mutual coupling.
Design Attributes	- Functional, visually appealing, and user-friendly. - Simple and elegant design facilitates easy implementation, integration, and maintenance.

5.2 Recommendations and Future work

This study provides a thorough exploration of the experimental results, highlighting the presence of prominent harmonics in the return loss. These harmonics are primarily attributed to the complexities involved in the fabrication process. The appearance of these harmonics indicates that the fabrication process needs to be more precise, especially concerning the feedline with arrays, to achieve the desired performance without such anomalies.

The research focuses on a single-band antenna utilizing the backline feed technique. This method has shown promise, but the practical application revealed that the complexity of accurately manufacturing the antenna can lead to unintended harmonics. These harmonics can adversely affect the antenna's performance, suggesting that further investigation is necessary to understand and mitigate these effects.

To address these issues, future studies should delve into the origins of these harmonics. One critical area for exploration is the material properties of the proposed

antenna. Different materials can have varied responses to fabrication processes and environmental conditions, which could contribute to the observed harmonics. By thoroughly analysing these material properties, researchers can identify potential improvements or adjustments needed to reduce these effects.

Another essential factor is the precision of the fabrication process. Even minor deviations in manufacturing can lead to significant performance changes. Therefore, achieving greater precision in the fabrication process is crucial. This could involve advanced manufacturing techniques, stricter quality control measures, or the development of new methods to ensure that the antenna is produced exactly as designed.

It can be concluded that, while the current study demonstrates the potential of the backline feed technique for single-band antennas, it also highlights the need for more precise fabrication methods. Addressing the fabrication complexities and understanding the material properties in greater detail will be vital steps in eliminating harmonics and enhancing the antenna's performance. This research lays the groundwork for these future investigations, offering a promising path forward for improving antenna design and application.

REFERENCES

- Anchidin, L., Lavric, A., Mutescu, P.-M., Petrariu, A. I., & Popa, V. (2023). The Design and Development of a Microstrip Antenna for Internet of Things Applications. *Sensors*, 23(3), 1062. <https://doi.org/10.3390/s23031062>
- Abdulhussein, A. M., Khidhir, A. H., & Naser, A. A. (2021). Design and Implementation of Microstrip Patch Antenna Using Inset Feed Technique for 2.4 GHz Applications. *International Journal of Microwave and Optical Technology*, 16(4).
- Abdullah, R. G. (2017). Accessibility and development. A case study from rural sarawak, Malaysia. *International Journal of Business and Society*, 18(S4).791-799
- Aghaedah, T., & Oti, T. (n.d.). 5G Technology and its future prospects: a review. <https://doi.org/10.13140/RG.2.2.26625.47202>
- Aji, G. M., Wibisono, M. A., & Munir, A. (2016). High gain 2.4GHz patch antenna array for rural area application. Proceedings - *Asia-Pacific Conference on Communications, APCC 2016*. <https://doi.org/10.1109/APCC.2016.7581507>
- Aktar, M., Rana, Md. M., Sarker, N., & Hossain, Md. S. (2020). Comparative Analysis on Antenna Balun and Feeding Techniques of Step Constant Tapered Slot Antenna. *Journal of Sensor Technology*, 10(03). <https://doi.org/10.4236/jst.2020.103003>
- Gu, H., Qi, H., Zhao, Y., & Ge, L. (2024). Feeding-line-based decoupling patch antennas. *IET microwaves Antenn. Propagation* 18(8).593-600. (<https://doi.org/10.1049/mia2.12484>)
- T.-Y., Zhang, S., & Xiao, S. Q. (2023). Harmonic-Suppressed Dual-Resonance Decoupling Network With Near-Zero Insertion Loss for Patch Antenna Arrays. *IEEE Transactionson Antennas and Propagation*, 71(8), 6959-6964

<https://doi.org/10.1109/TAP.2023.3276579>

- Aida Abdi Diman, Karami, F., Rezaei, P., Amn-e-Elahi, A., Zahra Mousavirazi, Denidni, T. A., & Kishk, A. A. (2021). Efficient SIW-Feed Network Suppressing Mutual Coupling of Slot Antenna Array. *IEEE Transactions on Antennas and Propagation*, 69(9).6058-6063 <https://doi.org/10.1109/tap.2021.3069557>
- Kaabal, A., halaoui, M. E., Ahyoud, S., & Asselman, A. (2016). A Low Mutual Coupling Design for Array Microstrip Antennas Integrated with Electromagnetic Band-Gap Structures *Procedia Technology*,22, <https://doi.org/10.1016/j.protcy.2016.01.115>
- Ali, M. T., Aizat, Pasya, I., Mazlan Zaharuddin, M. H., & Ya'acob, N. (2011). E-shape microstrip patch antenna for wideband applications. 2011 *IEEE International RF and Microwave Conference,RFM 2011 Proceedings*.
<https://doi.org/10.1109/RFM.2011.6168785>
- Ali, M. T., Alias, H., Muhamud, S., & Tan, M. N. M. (2011). A 2 by 2 planar array antenna using aperture coupler technique. ISWTA 2011 - 2011 *IEEE Symposium on Wireless Technology and Applications*. <https://doi.org/10.1109/ISWTA.2011.6089394>
- Ali, U., Ullah, S., Kamal, B., Matekovits, L., & Altaf, A. (2023). Design, Analysis and Applications of Wearable Antennas: A Review. In *IEEE Access* (Vol. 11).
<https://doi.org/10.1109/ACCESS.2023.3243292>
- Al-Mumen, H., & Hamad, A. A. (2022). Design and characterization of an radio frequency reused energy system for nano-devices. *Bulletin of Electrical Engineering and Informatics*, 11(5). <https://doi.org/10.11591/eei.v11i5.4321>
- Amit Kumar, Jaspreet Kaur, R. S. (2013). Performance Analysis of Different Feeding Techniques. *International Journal of Emerging Technology and Advanced Engineering*, Volume 3(Issue 3).

- Bisht, S., Saini, S., Prakash, V., & Nautiyal, B. (2019). Study The Various Feeding Techniques of Microstrip Antenna Using Design and Simulation Using CST Microwave Studio. *International Journal of Emerging Technology and Advanced Engineering*, 4(9).
- Brito, T., Pereira, A. I., Lima, J., & Valente, A. (2020). Wireless sensor network for ignitions detection: An IoT approach. *Electronics (Switzerland)*, 9(6).
<https://doi.org/10.3390/electronics9060893>
- Campbell, M., & Mackay, K. J. (2009). Communicating the role of hunting for wildlife management *Human Dimensions of Wildlife*,14(1).
<https://doi.org/10.1080/10871200802545781>
- Chemkha, H., & Belkacem, A. (2020). Design of new inset fed rectangular microstrip patch antenna with improved fundamental parameters. *DTS 2020 - IEEE International Conference on Design and Test of Integrated Micro and Nano-Systems*.
<https://doi.org/10.1109/DTS48731.2020.9196068>
- Chien, S. I. J., Liu, X., & Ozbay, K. (2003). Predicting Travel Times for the South Jersey Real-Time Motorist Information System. *Transportation Research Record*, 1855.
<https://doi.org/10.3141/1855-04>
- Govigli, V. M., Alkhaled, S., Arnesen, T., Barlagne, C., Bjerck, M., Burlando, C., Melnykovich, M., Fernandez-Blanco, C. R., Sfeir, P., & Górriz-Mifsud, E. (2020). Testing a framework to co-construct social innovation actions: Insights from seven marginalized rural areas.*Sustainability(Switzerland)*,12(4).
<https://doi.org/10.3390/su12041441>
- Gupta, A., & Chawla, P. (2016). Fractal: Impact of feeding techniques on the radiation

- pattern of modified star triangular fractal. *Proceedings on 2015 1st International Conference on Next Generation Computing Technologies, NGCT 2015*.
<https://doi.org/10.1109/NGCT.2015.7375157>
- Hamoudi, H., Haddad, B., & Lognonne, P. (2013). Study of a L2 patch antennas array for GNSS/GPS network. *2013 7th European Conference on Antennas and Propagation, EuCAP 2013*.
- Hussain, M. B., Butt, M., Nadeem, Z., Zahid, M., & Amin, Y. (2023). Design of Dual-Band Microstrip Patch Antenna for Wireless Local Area Network Applications †. *Engineering Proceedings*, 46(1). <https://doi.org/10.3390/engproc2023046003>
- Kapusuz, K. Y., Lemey, S., & Rogier, H. (2018). Substrate-Independent Microwave Components in Substrate Integrated Waveguide Technology for High-Performance Smart Surfaces. *IEEE Transactions on Microwave Theory and Techniques*, 66(6).
<https://doi.org/10.1109/TMTT.2018.2823319>
- Khalil Ibrahim, S., & Jebur, Z. T. (2021). Design and Analysis Performance of Compact Coronavirus-Shaped Microstrip Patch Antenna for Wireless- Applications. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3833883>
- Khare, A., Nema, R., Gour, P., & Thakur, R. K. (2010). New Multiband E-Shape Microstrip Patch Antenna on RT DUROID 5880 Substrate and RO4003 Substrate for Pervasive Wireless Communication. *International Journal of Computer Applications*, 9(8).
<https://doi.org/10.5120/1408-1901>
- Knott, P. (2013). Design of a printed dipole antenna array for a passive radar system. *International Journal of Antennas and Propagation*, 2013.
<https://doi.org/10.1155/2013/179296>
- Kumar, R., Shri, B., & Jhabarmal, J. (n.d.) (2016). EMERGING TRENDS IN WIRELESS

COMMUNICATION TECHNOLOGIES. *Microwave Studio. International Journal of Emerging Technology and Advanced Engineering*. 8(9)

Kumari, N. P., Gowri, R., Ranjan, P., & Kuchhal, P. (2014). Design of double sided metamaterial antenna for mobile handset applications. 2014 *International Conference on Signal Processing and Integrated Networks, SPIN 2014*. <https://doi.org/10.1109/spin.2014.6777040>

Kuschel, H., Heckenbach, J., Müller, S., & Appel, R. (2010). Countering stealth with passive, multi-static, low frequency radars. *IEEE Aerospace and Electronic Systems Magazine*, 25(9). <https://doi.org/10.1109/MAES.2010.5592986>

Kyei, A., Sim, D. U., & Jung, Y. B. (2017). Compact log-periodic dipole array antenna with bandwidth-enhancement techniques for the low frequency band. *IET Microwaves, Antennas and Propagation*, 11(5). <https://doi.org/10.1049/iet-map.2016.0611>

Li, C., & Schreurs, D. M. M. P. (2017). Fundamentals of microwave engineering. In *Principles and Applications of RF/Microwave in Healthcare and Biosensing*. <https://doi.org/10.1016/B978-0-12-802903-9.00001-1>

Lova Raju, K., & Vijayaraghavan, V. (2022). Wireless Communication Technologies with IoT-Based Cloud-Enabled Service for Smart Agriculture Monitoring System. 2022 *International Conference on Innovative Trends in Information Technology, ICITIIT 2022*. <https://doi.org/10.1109/ICITIIT54346.2022.9744230>

Mahmoodha, S., & Dorathy, P. E. I. (2021). Design of novel stratified structure inset feed patch antenna for 5G evolutions. *International Research Journal of Modernization in Engineering Technology and Science*, 3(1), 1–15. <https://www.irjmets.com>

Mazen, K., Emran, A., Shalaby, A. S., & Yahya, A. (2021). Design of Multi-band Microstrip Patch Antennas for Mid-band 5G Wireless Communication. *International Journal of*

Advanced Computer Science and Applications,12(5).

<https://doi.org/10.14569/IJACSA.2021.0120557>

Miftahul Amri, M., & Ramadhan Faqih, G. (2022). Recent Trends in Fractal Antenna Research for In-body Communications. *Bincang Sains Dan Teknologi*, 1(02).

<https://doi.org/10.56741/bst.v1i02.160>

Misra, G., Agarwal, A., & Agarwal, K. (2015). Design and Performance Evaluation of Microstrip Antenna for Ultra-Wideband Applications Using Microstrip Feed. *American Journal of Electrical and Electronic Engineering*, 3(4).

Nour, A. A., Fezai, F., & Monediere, T. (n.d.).(2017) Comparison of Different Feeding Techniques of a Low-Profile Dual-band Circularly Polarized Microstrip Antenna.

Nurvitasari, R., Hariyadi, T., & Mulyanti, B. (2014). *Antena mikrostrip monopole pita lebar segi empat untuk aplikasi dvb-t. electrans*, 13(2).

Olan-Nunez, K. N., Murphy-Arteaga, R. S., & Colin-Beltran, E. (2020). Miniature Patch and Slot Microstrip Arrays for IoT and ISM Band Applications. *IEEE Access*, 8. <https://doi.org/10.1109/ACCESS.2020.2998739>

Petrov, V., Komarov, M., Moltchanov, D., Jornet, J. M., & Koucheryavy, Y. (2017). Interference and SINR in Millimeter Wave and Terahertz Communication Systems With Blocking and Directional Antennas. *IEEE Transactions on Wireless Communications*, 16(3). <https://doi.org/10.1109/TWC.2017.2654351>

Prados-Garzon, J., Ramos-Munoz, J. J., Ameigeiras, P., Andres-Maldonado, P., & Lopez-Soler, J. M. (2017). Modeling and dimensioning of a virtualized MME for 5G mobile networks. In *IEEE Transactions on Vehicular Technology* (Vol. 66, Issue 5). <https://doi.org/10.1109/TVT.2016.2608942>

Rana, M. S., Hossain, S., Rana, S. B., & Rahman, M. M. (2023). Microstrip patch antennas

- for various applications: a review. In *Indonesian Journal of Electrical Engineering and Computer Science* (Vol.29,Issue3).<https://doi.org/10.11591/ijeecs.v29.i3.pp1511-1519>
- Rana, M. S., & Smieeee, M. M. R. (2022). Design and analysis of microstrip patch antenna for 5G wireless communication systems. *Bulletin of Electrical Engineering and Informatics*, 11(6). <https://doi.org/10.11591/eei.v11i6.3955>
- Ranjan, P., & Mishra, S. (2013). Design of Circularly Polarized Rectangular Patch Antenna with single cut. *Conference on Advances in Communication and Control Systems, CAC2S 2013*, 2013(Cac2s).
- Sandi, E., Rusmono, Diamah, A., & Vinda, K. (2020). Ultra-wideband microstrip array antenna for 5G millimeter-wave applications. *Journal of Communications*, 15(2). <https://doi.org/10.12720/jcm.15.2.198-204>
- Saxena, N., & Rajawat, A. (2020). Design and Analysis of Slotted Microstrip Patch Antenna Using DGS for S Band. *Advances in Intelligent Systems and Computing*, 1089. https://doi.org/10.1007/978-981-15-1483-8_1
- Al-Hadeethi, Y. T., Hatem, M. N., & Hassan, A. S. (2025). Design of a compact inset feed microstrip antenna for 5G applications with enhanced MIMO performance. *Engineering, Technology & Applied Science Research*, 15(1), 10094 [<https://doi.org/10.48084/etasr.10094>] (<https://doi.org/10.48084/etasr.10094>)
- Sulaiman, S., & Halamy, S. (2021). ICT education as a catalyst to bridge digital divide: The roles of UiTM Sarawak in rural areas. *International Journal of Advanced Research in Education and Society*, 3(2), 174-181.
- Sunitiyoso, Y., Wicaksono, A., Pambudi, N. F., Rahayu, W. A., Nurdayat, I. F., Hadiansyah, F., Nuraeni, S., & Muhammad, A. A. (2023). Future of mobility in Jakarta

- Metropolitan Area: A Multi-Stakeholder scenario planning. *Transportation Research Interdisciplinary Perspectives*, 19. <https://doi.org/10.1016/j.trip.2023.100810>
- Tabassum, M., Alhawas, T., & Saibukandu, A. (2015). A Preliminary Study on Performance Evaluation of Mobile Telecommunications Infrastructure in Kuching, Sarawak. <https://doi.org/10.13140/RG.2.1.5006.4480>
- Tecpoyotl-Torres, M., Vera Dimas, J. G., Castaneda-Sotelo, R., & Vargas-Bernal, R. (2013). Rectangular patch antenna array with defect ground structure for Wi-Fi. 2013 *IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2013*. <https://doi.org/10.1109/ROPEC.2013.6702732>
- Theissen, M., Kern, L., Hartmann, T., & Clausen, E. (2023). Use-Case-Oriented Evaluation of Wireless Communication Technologies for Advanced Underground Mining Operations. *Sensors*, 23(7). <https://doi.org/10.3390/s23073537>
- Triezenberg, H. A., Riley, S. J., & Gore, M. L. (2016). A test of communication in changing harvest behaviors of deer hunters. *Journal of Wildlife Management*, 80(5). <https://doi.org/10.1002/jwmg.21078>
- Vera Dimas, J. G., Tecpoyotl Torres, M., Vargas Chablé, P., Damian Morales, J. A., Escobedo Alatorre, J., & Koshevaya, S. (2019). *Individual Patch Antenna and Antenna Patch Array for Wi-Fi Communication. Programación Matemática y Software*, 2(2010). <https://doi.org/10.30973/progmat/2010.2.1/2>
- Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big Data in Smart Farming – A review. In *Agricultural Systems* (Vol.153). <https://doi.org/10.1016/j.agsy.2017.01.023>
- Muhammad, A. Y., Yusuf, S., Musa, S., Man, K. L., & Litvinova, E. (2021, January 1). Design and Simulation of Microstrip Patch Array Antenna for Wireless

- CommunicationSystem. <https://www.researchgate.net/publication/357352959>
- Yang, Q., Sisiopiku, V., Arnold, J. A., Pisano, P., & Nelson, G. G. (2000). Assessment of rural intelligent transportation system wireless communications solutions. *Transportation Research Record*, 1739. <https://doi.org/10.3141/1739-07>
- Yassin, M. E., Mohamed, H. A., Abdallah, E. A. F., & El-Hennawy, H. S. (2019). Single-fed 4G/5G multiband 2.4/5.5/28 GHz antenna. *IET Microwaves, Antennas and Propagation*, 13(3). <https://doi.org/10.1049/iet-map.2018.5122>
- Zaakri, S., Zenkouar, L., & Bri, S. (2013). Conception of Bi-band rectangular microstrip array antenna. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 12(1).
- Zhang, J., Zhang, X., Imran, M. A., Evans, B., Zhang, Y., & Wang, W. (2017). Energy efficient hybrid satellite terrestrial 5G networks with software defined features. *Journal of Communications and Networks*, 19(2). <https://doi.org/10.1109/JCN.2017.000024>
- Zhang, Y., Love, D. J., Krogmeier, J. V., Anderson, C. R., Heath, R. W., & Buckmaster, D. R. (2021). Challenges and Opportunities of Future Rural Wireless Communications. *IEEE* 59(12). <https://doi.org/10.1109/MCOM.001.2100280>
- Zhao, M., Ye, R. J., Chen, S. T., Chen, Y. C., & Chen, Z. Y. (2023). Realization of Forest Internet of Things Using Wireless Network Communication Technology of Low-Power Wide-Area Network. *Sensors*, 23(10). <https://doi.org/10.3390/s23104809>
- hauraya, A., Zhang, S., Whittow, W. G., Seager, R., Vardaxoglou, J. C., & Dias, T. (2015). Embroidered wire dipole antennas using novel copper yarns. *IEEE Antennas and Wireless Propagation Letters*, 14, 638–641.
- Adamu, S. A., Masri, T., Abidin, W. A. W. Z., Ping, K. H., & Babale, S. A. (2018). High-

- gain modified antipodal Vivaldi antenna for ultra-wideband applications. *Journal of Telecommunication, Electronic and Computer Engineering*, 10(1–12), 55–59.
- Ba, H. C., Shirai, H., & Ngoc, C. D. (2014). Analysis and design of antipodal Vivaldi antenna for UWB applications. In *Proceedings of the IEEE 5th International Conference on Communications and Electronics*, (pp. 391–394).
- Capano, D. E. (2014). Antenna basics, antenna types, antenna functions. *Control Engineering*, 61(9), 18–20.
- Chen, L., Lei, Z., Yang, R., Fan, J., & Shi, X. (2015). A broadband artificial material for gain enhancement of antipodal tapered slot antenna. *IEEE Transactions on Antennas and Propagation*, 63(1), 395–400.
- Dastranj, A. (2015). Wideband antipodal Vivaldi antenna with enhanced radiation parameters. *IET Microwaves, Antennas & Propagation*, 9(15), 1755–1760.
- Elmansouri, M. A., & Filipovic, D. S. (2012). Low-dispersion spiral antennas. *IEEE Transactions on Antennas and Propagation*, 60(12), 5522–5530.
- Elsheakh, D. M., Eltresy, N. A., & Abdallah, E. A. (2017). Ultra wide bandwidth high gain Vivaldi antenna for wireless communications. *Progress In Electromagnetics Research Letters*, 69, 105–111.
- Fang, G., & Sato, M. (2002). Optimization of Vivaldi antenna for demining by GPR. In *Proceedings of the 2002 Interim International Symposium on Antennas and Propagation* (pp. 263–266).
- Fei, P., Jiao, Y. C., Hu, W., & Zhang, F. S. (2011). A miniaturized antipodal vivaldi antenna with improved radiation characteristics. *IEEE Antennas and Wireless Propagation Letters*, 10, 127–130.
- Gao, X., Shen, Z., & Hua, C. (2015). Conformal VHF log-periodic balloon antenna. *IEEE*

- Transactions on Antennas and Propagation*, 63(6), 2756–2761.
- Huang, D., Yang, H., Wu, Y., Zhao, F., & Liu, X. (2018). A high-gain antipodal Vivaldi antenna with multi-layer planar dielectric lens. *Journal of Electromagnetic Waves and Applications*, 32(4), 403–412.
- IEEE Antennas & Propagation Society. (2014). IEEE standard for definitions of terms for antennas. *IEEE Std 145-2013 (Revision of IEEE Std 145-1993)*, 2013, 1–50.
- Jacobs, B., Odendaal, J. W., & Joubert, J. (2012). An improved design for a 1–18 GHz double-ridged guide horn antenna. *IEEE Transactions on Antennas and Propagation*, 60(9), 4110–4118.
- Kerarti, D. Z., Marouf, F. Z., & Meriah, S. M. (2012). New tapered slot vivaldi antenna for UWB applications. In *Proceedings of the International Conference on Microelectronics*, (pp. 5–8).
- Kumar, R., & Suraj, P. (2017). Antipodal Vivaldi antenna for UWB communication with metamaterial. In *Proceedings of the International Conference on Inventive Systems and Control*, (pp. 1–5).
- Kushwaha, N., & Kumar, R. (2014). Study of different shape electromagnetic band gap (EBG) structures for single and dual band applications. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 13(1), 16–30.
- Li, Z., Tan, L., Kang, X., Su, J., Guo, Q., Yang, Y. L., & Wang, J. (2016). A novel wideband end-fire conformal antenna array mounted on a dielectric cone. *Applied Computational Electromagnetics Society Journal*, 31(8), 933–942.
- Natarajan, R., George, J. V., Kanagasabai, M., & Shrivastav, A. K. (2015). A compact antipodal Vivaldi antenna for UWB applications. *IEEE Antennas and Wireless Propagation Letters*, 14, 1557–1560.

- Pandey, G. K., Singh, H. S., Bharti, P. K., Pandey, A., & Meshram, M. K. (2014). High gain Vivaldi antenna for radar and microwave imaging applications. *International Journal of Signal Processing Systems*, 3(1), 35–39.
- Ren, L. S., Li, F., Zhao, J. J., Zhao, G., & Jiao, Y. C. (2010). A novel compact UWB antenna with dual band-notched characteristics. *Journal of Electromagnetic Waves and Applications*, 24(11–12), 1521–1529.
- Sarkar, D., & Srivastava, K. V. (2013). SRR-loaded antipodal Vivaldi antenna for UWB applications with tunable notch function. In *21st International Symposium on Electromagnetic Theory*, (pp. 466–469).
- Singha, R., & Vakula, D. (2015). Corrugated antipodal Vivaldi antenna using spiral shape negative index metamaterial for ultra-wideband application. In *Proceedings of IEEE International Conference on Signal Processing and Communication Engineering Systems*, (Vol. 5880, pp. 179–183).
- Tang, H. B., & Shui, X. Z. (2013). Design of antipodal Vivaldi antenna array. *Applied Mechanics and Materials*, 380–384, 3465–3468.
- Teni, G., Zhang, N., Qiu, J., & Zhang, P. (2013). Research on a novel miniaturized antipodal Vivaldi antenna with improved radiation. *IEEE Antennas and Wireless Propagation Letters*, 12, 417–420.
- Venkatarayalu, N. V., & Gan, Y. B. (2010). Design of a tapered slot array antenna for UWB through-wall radar. In *Proceedings of IEEE International Symposium on Antennas and Propagation and CNC-USNC/URSI Radio Science Meeting - Leading the Wave*, (pp. 1–4).
- Vignesh, N., Sathish Kumar, G. A., & Brindha, R. (2014). Design and development of a tapered slot Vivaldi antenna for ultra-wideband application. *International Journal of*

- Advanced Research in Computer Science and Software Engineering*, 4(5), 174–178.
- Wang, P., Zhang, H., Wen, G., & Sun, Y. (2012). Design of a modified 6-18 GHz balanced antipodal Vivaldi antenna. *Progress in Electromagnetic Research*, 25, 271–285.
- Yang, Z., Jingjian, H., Weiwei, W., & Naichang, Y. (2017). An antipodal Vivaldi antenna with band-notched characteristics for ultra-wideband applications. *AEU - International Journal of Electronics and Communications*, 76, 152–157.
- Yimdjo Poffelie, L. A., Soh, P. J., Yan, S., & A. E. Vandenbosch, G. (2016). A high-fidelity all-textile UWB antenna with low back radiation for off-body WBAN applications. *IEEE Transactions on Antennas and Propagation*, 64(2), 757–760.
- Zeng, J. (2013). Compact electromagnetic band-gap structures (EBG) and its applications in antenna systems. In *Master's Thesis, University of Waterloo* (pp. 1–7).
- Zhang, J., Zhang, X., & Xiao, S. (2017). Antipodal Vivaldi antenna to detect UHF signals that leaked out of the joint of a transformer. *International Journal of Antennas and Propagation*, 2017, 1–13.
- Zhu, F., & Gao, S. (2013). Compact elliptically tapered slot antenna with nonuniform corrugations for ultra-wideband applications. *Radio Engineering*, 22(1), 276–280.

APPENDICES

Appendix A: Journal Publications

1. **Hasan, M. F.**, Mat, D. A. A., & Sayed, M. A. (2024). Modified back-line inset feed 1×4 array microstrip antenna for 5.8 GHz frequency band. *Indonesian Journal of Electrical Engineering and Computer Science*,36(2),892–900.
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