DESIGN AND OPTIMIZATION OF MICROSTRIP ARRAY ANTENNA USING BOTH-SIDED MICROWAVE INTEGRATED CIRCUIT FOR GAIN ENHANCEMENT

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M.Sc. ENGINEERING THESIS

DEPARTMENT OF ELECTRICAL, ELECTRONIC AND
COMMUNICATION ENGINEERING
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DHAKA, BANGLADESH

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
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By

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DECLARATION

I hereby declare that the study reported in this thesis entitled as above has been composed solely by me and it has not been submitted, in whole or in part, in any previous application for any degree. Further I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged or cited in the reference Section.

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ABSTRACT

Design and Optimization of Microstrip Array Antenna using Both-Sided Microwave Integrated Circuit for Gain Enhancement

In the contemporary landscape of communication systems, Microstrip Patch Antennas (MPAs) have gained immense popularity owing to their low profile, cost-effectiveness, and fabrication simplicity. In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints and low-profile microstrip antennas may be potent candidate. Despite their widespread use, MPAs exhibit a notable drawback in the form of low gain response. Researchers are actively engaged in overcoming this limitation, exploring diverse techniques to enhance MPA performance for specific applications.

High gain antennas are particularly desirable in practical scenarios, providing extended coverage compared to their low gain counterparts. Microstrip array antennas emerge as promising candidates for achieving high gain, leveraging multiple radiating elements on a single substrate for versatile wireless applications. This thesis delves into the background and current state of the problem surrounding MPA gain limitations. Various strategies reported in the literature to address these limitations include the use of parasitic patches, thick substrates, multi-resonator techniques, conventional array techniques, large ground planes, and stacked patches. However, each technique presents its own set of drawbacks, such as increased antenna size, complexity in multilayer fabrication, and additional impedance matching circuit requirements. Notably, conventional array antennas necessitate impedance matching circuits and transmission lines for connecting array elements, leading to bulkiness and increased internal losses, thereby compromising efficiency.

In response to these challenges, the thesis proposes the exploration of a novel technique both-sided MIC. Operating at microwave frequencies, this technique holds promise in mitigating the drawbacks associated with existing strategies. The thesis aims to investigate the design and optimization of a Microstrip Array Antenna utilizing both-sided MIC for gain enhancement. Through comprehensive analysis and experimentation, the goal is to establish the efficacy of this innovative approach in achieving high gain while addressing the limitations posed by traditional methods. The outcomes of this research are expected to contribute significantly to the advancement of micro strip antenna technology, opening new avenues for practical and efficient wireless communication systems.

সারসংক্ষেপ

Design and Optimization of Microstrip Array Antenna using Both-Sided Microwave Integrated Circuit for Gain Enhancement

মাইক্রোস্ট্রিপ এ্যান্টিনা একধরণের অভ্যন্তরীণ এ্যান্টিনা যা প্রিন্টেড সার্কিটবোর্ডে ফটোলিথোগ্রাফিক কৌশল ব্যবহার করে তৈরী করা হয়। এটি মূলত তিনটি উপাদানে গঠিত- রেডিয়েটিং প্যাচ, ডাইইলেকট্রিক সাবস্ট্রেট এবং গ্রাউন্ড প্লেন। সাম্প্রতিক সময়ে ওয়ারলেস কমিউনিকেশন সিস্টেমে মাইক্রোস্ট্রিপ প্যাচ এ্যান্টিনা (এমপিএ) তার কিছু সহজাত বৈশিষ্ট্য যেমন- স্বল্প ওজন, দামে সস্তা এবং কনজুমার প্রোডাক্টের গায়ে সহজে স্থাপনযোগ্য ইত্যাদি বৈশিষ্ট্যের কারণে ব্যাপক জনপ্রিয়তা অর্জন করেছে। আকাশযান, মহাকাশযান, ইউএভি, মিসাইল ইত্যাদি স্থান যেখানে সাইজ, ওজন, পরফম্যান্স, এ্যারোডাইনামিক আকৃতি ইত্যাদি মূখ্য বিবেচ্য বিষয় সে সকল স্থানে মাইক্রোস্ট্রিপ এন্টিনা তার সহজাত বৈশিষ্ট্যের কারণে অত্যন্ত ব্যবহার উপযোগী হতে পারে। সহজাত বৈশিষ্টের কারণে অনেক ধরনের সুবিধার পাশাপাশি এর কিছু অসুবিধাও আছে। যার মধ্যে উল্লেখযোগ্য হচ্ছে এর লো গেইন। লো গেইন হওয়ার কারণে এর কাভারেজও স্বল্প হয়ে থাকে। কিন্তু বর্ণিত ব্যবহার সমূহে কাভারেজ তথা হাই গেইন এর প্রয়োজন হয়ে থাকে। মাইক্রোস্ট্রিপ এন্টিনার গেইন বর্ধনের জন্য অনেক ধরনের গবেষণা হয়েছে। মাইক্রোস্ট্রিপ এন্টিনার রেডিয়েটিং এলিমেন্ট বাড়িয়ে তথা এ্যারে এর ব্যবহারের মাধ্যমে গেইন বর্ধন করা সম্ভব। কিন্তু এর ক্ষেত্রে প্রত্যেকটি পৃথক এলিমেন্টকে আলাদাভাবে ইলেকট্রিক এক্সাইটেশন প্রদান করার প্রয়োজন হয়। সাধারণ প্রচলিত এ্যারে সমূহে প্রত্যেকটি এলিমেন্টে মাইক্রোস্ট্রিপ লাইনের মাধ্যমে সরবরাহ প্রদান করা হয়ে থাকে। এক্ষেত্রে ফিডিং লাইনে কিছুটা লস হয় যা গেইন তথা কর্মদক্ষতায় কিছুটা নেতিবাচক প্রভাব ফেলে। তাছাড়া এ ব্যবস্থাপনায় ইম্পিড্যান্স মেচিং এর জন্য পৃথক ব্যবস্থার প্রয়োজন হয় যা ফিডিং সার্কিটকে জটিল করে তোলে।

প্রচলিত মাইক্রোস্ট্রিপ এ্যারে এন্টিনায় উল্লেখিত প্রতিকূলতাসমূহ মোকাবেলায় এই গবেষণায় বোথ-সাইডেড এমআইসি (মাইক্রোস্ট্রিপ ইন্টিগ্রেটেড সার্কিট) পদ্ধতির অবতারণা করা হয়েছে। বোথ-সাইডেড এমআইসি এমন একটি ব্যবস্থা যেখানে সাবস্ট্রেটের উভয় পাশে ট্রান্সমিশন লাইন সংযুক্ত করা হয়েছে। এক্ষেত্রে সাবস্ট্রেটের উপরিভাগ অর্থ্যাৎ যে পাশে রেডিয়েটিং এলিমেন্ট রয়েছে সে পাশে মাইক্রোস্ট্রিপ লাইন এবং গাউন্ড সাইডে স্লট লাইন ব্যবহৃত হয়েছে। মাইক্রোস্ট্রিপ লাইন ও স্লট লাইনের প্রস্ততা এমনভাবে মেইনটেইন করা হয় যেন স্লট লাইনের ইম্পিডেন্স মাইক্রোস্ট্রিপ লাইনের দ্বিগুণ হয়। যথাযথ ইম্পিডেন্স ম্যাচিং এর জন্য মাইক্রোস্ট্রিপ লাইনে কোয়ার্টার ওয়েভ ল্যাম্ব ট্রান্সফর্মার ব্যবহার করায় রেডিয়েটিং প্যাচ এ ইনসেট ফিডিং/ নোচিং এর প্রয়োজন হয় না। মাইক্রোস্ট্রিপ এবং স্লট লাইনের মধ্যে সরাসরি কোন বৈদ্যুতিক সংযোগ নাই কিন্তু তারা মিচ্যুয়ালি কাপলড। এক্ষেত্রে সাবট্রেটের উপরিভাগে ফিডিং লাইনে কপারের ব্যবহার যথেষ্ট কমে যায়। ফলে কপার লস এবং তাপজনিত লস কম হয় এবং পরিনামে এন্টিনার গেইন ও কর্মদক্ষতা যথেষ্ট বৃদ্ধি পায়। এই গবেষণার উল্লেখ্যযোগ্য অবদান হচ্ছে ফিডিং লাইনের জটিলতা পরিহার করে সরল বোথ-সাইডেড এমআইসি ব্যবহারের মাধ্যমে মাইক্রোস্ট্রিপ এন্টিনার গেইন এবং কর্মদক্ষতা উল্লেখযোগ্য হারে বর্ধন করা যা যোগাযোগ ব্যবস্থাপনায় সম্ভাবনার এক নতুন দুয়ার উম্মোচনে সহায়ক।

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LIST OF ABBREVIATIONS

ADS	Advance Design System
AF	Array Factor
AI	Artificial Intelligence
BW	Bandwidth
dB	Decibel
dBi	Decibels relative to Isotropic
DOI	Digital Object Identifier
FNBW	First Null Beam Width
FR-4	Fiberglass – Reinforced Epoxy
GHz	Gigahertz
HF	High Frequency
Hz	Hertz
HPBW	Half Power Beam Width
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISSN	International Standard Serial Number
IoT	Internet of Things
MHz	Megahertz
MIC	Microwave Integrated Circuit
MIMO	Multiple Input Multiple Output
MMIC	Monolithic Microwave Integrated Circuit
mm	Millimeter
MPA	Microstrip Patch Antenna
PTFE	Polytetrafluoroethylene

RCS	Radar Cross Section
RL	Return Loss
RF	Radio Frequency
SAR	Synthetic Aperture Radar
SIW	Substrate Integrated Waveguide
SNR	Signal – to – Noise Ratio
UAV	Unmanned Aerial Vehicle
VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
W-band	Wide Band
WLAN	Wireless Local Area Network
5G	Fifth Generation
3-D	Three-Dimensional
2-D	Two-Dimensional

LIST OF SYMBOLS

Y	Admittance
ω	Angular Frequency
e_c	Antenna Conduction Efficiency
e_d	Antenna Dielectric Efficiency
G (θ,φ)	Antenna Gain
Z_A	Antenna Impedance
e_{cd}	Antenna Radiation Efficiency
e_r	Antenna Reflection Efficiency
e_t	Antenna Total Efficiency
f_o	Center Frequency
Z_c	Characteristic Impedance of Transmission Line
G	Conductance
β	Deference in Phase Between Elements
ε_r	Dielectric Constant of Substrate
D	Directivity
TM_{010}	Dominate Mode
ε_{reff}	Effective Dielectric Constant
L_{eff}	Effective Length of the Patch
ΔL	Extension in Length of Patch due to Fringing Field
L_f	Feed to Feed Length
μ_0	Free Space Permeability
ε_0	Free Space Permittivity
λ_0	Free-Space Wavelength

q	Fringe Factor
Z_S	Impedance of Slot Line
P_{in}	Incident Power
V_P^+	Incident Voltage Wave at Port P
L	Length of Radiating Element/Patch
R_L	Load Resistance
f_l	Lower Cut-Off Frequency
w_m	Micro Strip Line Width
Z_0	Micro Strip Line Impedance
$\Delta L/h$	Normalized Extension in Length of Patch due to Fringing Field
Ω	Ohm
L_p	Patch to Patch Length
Ψ	Progressive Phase
w_t	Quarter Wavelength Transformer Width
Z_1	Quarter Wavelength Transformer Impedance
U	Radiation Intensity
X_A	Radiation Reactance
R_r	Radiation Resistance
V^i	Reflected Voltage
S_{ij}	Reflection Coefficient
S_{11}	Reflection Coefficient at Port 1
S_{22}	Reflection Coefficient at Port 2
V_P^-	Reflected Voltage Wave at Port P
P_{ref}	Reflected Power
f_r	Resonant Frequency

[S]	Scattering Matrix
w_s	Slot Line Width
v_0	Speed of Light
h	Substrate Height
B	Susceptance
t	Thickness of Patch
R_{in}	The Resonant Input Resistance
Y_{in}	Total Resonant Input Admittance
S_{pq}	Transmission Coefficient
V^j	Transmitted Voltage
S_{12}	Transmission Coefficient from Port 2 to Port 1
S_{13}	Transmission Coefficient from Port 3 to Port 1
S_{23}	Transmission Coefficient from Port 3 to Port 2
f_h	Upper Cut-Off Frequency
λ	Wavelength in the Dielectric (Substrate)
W	Width of Radiating Element/Patch
W/h	Width-to-Height Ratio

CHAPTER 1
INTRODUCTION

1.1 Overview

The rapid evolution of communication technology in the modern era has propelled Microstrip Patch Antennas (MPAs) to the forefront of wireless communication systems. Renowned for their low profile, lightweight construction, cost-effectiveness, and ease of fabrication, MPAs have become integral components in various communication applications [1-2]. However, a persistent challenge has impeded their widespread adoption namely, the limitation in gain response, which hinders their effectiveness in certain scenarios [1].

In response to this challenge, researchers have extensively explored diverse strategies to augment the gain of MPAs. Previous studies have investigated methods such as incorporating parasitic patches, using thick substrates, employing conventional array techniques, and implementing large ground plane and stack patches [5-7]. While these approaches have demonstrated promise in enhancing gain, they often introduce trade-offs, such as increased antenna size, fabrication complexity, and the need for additional impedance matching circuits.

Against this backdrop, recent attention has shifted towards an innovative solution both-sided MIC techniques. This novel approach leverages transmission lines on both sides of the substrate, operating at microwave frequencies [9]. The literature suggests that this technique has the potential to address the low-gain issue without compromising the compactness and simplicity of the antenna system.

In the context of this evolving landscape, the present research endeavors to contribute to the field by proposing a microstrip array antenna design with multiple radiating elements. The key innovation lies in the incorporation of both-sided MIC techniques for feeding circuits, aiming to achieve enhanced gain characteristics. The objectives of the study include the design of the array antenna, development of feeding circuits using both-sided MIC techniques, and optimization of the entire system for superior performance.

By synthesizing insights from existing literature and pushing the boundaries of current research, this project aspires to offer a novel solution to the low-gain challenge in microstrip patch antennas. The envisioned outcome is a high-gain microstrip array antenna that not only addresses the limitations of traditional techniques but also aligns with the growing demand for compact, efficient, and versatile communication systems. Through this endeavor, the research aims to contribute valuable insights to the ongoing dialogue surrounding the optimization of microstrip antennas for contemporary communication applications.

1.2 Background and Present State of the Problem

In the modern era of communication the Microstrip Patch Antenna (MPA) has gained widespread popularity for its attributes of low profile, cost-effectiveness, and ease of fabrication [1-2]. However, the prevalent issue of low gain response has prompted researchers to explore innovative solutions to enhance the efficacy of MPAs for specific communication applications. High gain antennas are particularly desirable in practical scenarios, as they offer extended coverage compared to their low gain counterparts. The Microstrip Array Antenna emerges as a promising candidate in this context, capable of providing high gain by incorporating multiple radiating elements on a single substrate, rendering it suitable for various wireless applications [4-6]. A plethora of strategies have been documented in the literature to address the low gain challenges associated with MPAs [7-11]. These strategies include the utilization of parasitic patches [7], employing a thick substrate [8], implementing multi-resonator techniques, employing conventional array techniques [9], and utilizing techniques such as large ground planes and stack patches [10]. However, each of these techniques comes with its own set of drawbacks. For instance, increasing the number of parasitic patches can result in a larger antenna footprint. Additionally, multilayer fabrication of antennas proves to be intricate. While conventional array antennas are effective in constructing arrays, they necessitate additional impedance matching circuits, contributing to increased bulkiness. Moreover, the need for transmission lines to connect every array element can lead to elevated internal losses, consequently decreasing overall efficiency [10-12]. To overcome the aforementioned limitations, the both-Sided MIC technique, operating at microwave frequencies, is emerging as a novel and promising avenue for further research. This technique holds the potential to address the downsides associated with other methodologies, offering a more efficient and compact solution for enhancing the gain response of Micro strip Patch Antennas. The exploration of this innovative approach opens up new possibilities for advancing the practicality and performance of MPAs in diverse communication applications.

1.3 Research Motivation

The motivation behind the proposed research stems from the ever-growing significance of Microstrip Patch Antennas (MPAs) in modern communication systems and the persistent challenge of limited gain that hampers their full potential. As communication technology advances and becomes increasingly integrated into our daily lives, the demand for compact, efficient, and high-performance antennas becomes more critical. MPAs have emerged as frontrunners in meeting the demands of contemporary communication due to their inherent advantages such as low profile, lightweight construction, cost effectiveness, and ease of fabrication [1-2]. However, the drawback of low gain has been a bottleneck in fully exploiting the capabilities of these antennas, particularly in applications where extended coverage and higher signal strength are essential.

The exploration of various gain enhancing techniques in the existing literature reflects a collective effort to overcome this limitation. Strategies such as parasitic patches, thick substrates, conventional array techniques, and large ground planes have been investigated [5-7]. However, each method presents its own set of challenges, including increased antenna size, fabrication complexity, or the need for additional components, compromising the overall efficiency and applicability of the antenna system. The motivation to delve into both-sided MIC techniques arises from the potential of this innovative approach to reconcile the conflicting demands of high gain and compactness. By utilizing transmission lines on both sides of the substrate at microwave frequencies, both-sided MIC techniques offer a promising solution to the low-gain problem without introducing the drawbacks associated with traditional methods [9].

The envisioned impact of this research is the development of a high-gain microstrip array antenna that not only addresses the limitations of existing techniques but also aligns with the evolving requirements of modern communication systems. By contributing to the optimization of MPAs through both-sided MIC techniques, the research aims to provide a practical and efficient solution for applications requiring extended coverage and enhanced signal strength with a simple feeding network. In essence, the motivation for this research lies in the pursuit of advancing antenna technology to meet the escalating demands of contemporary communication, offering a novel and effective solution to the persistent challenge of limited gain in microstrip patch antennas. The anticipated outcomes aim to contribute valuable insights and innovations to the broader field of communication technology, fostering advancements that benefit diverse applications in our interconnected world.

1.4 Literature Review

A microstrip antenna is a type of antenna that operates at microwave frequencies and is commonly used in various communication systems. It consists of a thin conducting strip known as patch, typically made of copper or other metal, which is printed or etched onto a dielectric substrate, such as fiberglass or ceramic [1]. The conducting strip is usually fed with a transmission line, such as a coaxial cable or microstrip line, which provides the electromagnetic energy to the antenna. The utilization of Microstrip Patch Antennas (MPAs) has become widespread in modern communication systems due to their inherent advantages such as low profile, lightweight construction, cost-effectiveness, and ease of fabrication [1-2]. As a radiating component in communication systems with several applications, including wireless, radar, and satellite communication, microstrip patch antennas are becoming more and more popular as they provide such advantages [35-36]. They also offer feeding systems that are simple to construct and integrate with active a component, which makes them more appealing [37]. Among the various antenna parameters, antenna gain is a critical aspect of any communication since many applications require long-distance coverage. With microstrip patches in communication, a single patch may have difficulty in meeting the criteria. Making an array to improve antenna gain is an immediate option. In recent years, many studies on microstrip array antennas have been conducted [38-42].

High-gain antennas have an important influence on wireless communication. However, a persistent challenge associated with MPAs is their limited gain response, prompting researchers to explore various strategies to enhance their performance. Previous studies have investigated several techniques to address the low-gain issue of MPAs. One approach involves the use of parasitic patches, which has shown promise in increasing gain by manipulating the radiation pattern [5]. However, this method often leads to an increase in the antenna's physical size, limiting its applicability in space-constrained environments.

Another avenue explored in the literature is the use of a thick substrate to improve gain characteristics [6]. While this method has demonstrated effectiveness, it introduces complexity in the fabrication process and may not be suitable for applications requiring a compact antenna design. Conventional array techniques, such as employing multiple radiating elements, have also been employed to enhance the gain of microstrip antennas [7],

[10]. Despite offering improved performance, these approaches often necessitate additional impedance matching circuits, compromising the overall compactness of the antenna system. The literature also discusses large ground plane and stack patches as a means to achieve high gain in MPAs [7]. However, such techniques may not be ideal for certain applications due to their increased antenna size and potential manufacturing complexities. In addition, a lot of researchers have lately demonstrated a variety of methods that can be used with microstrip patch antennas to provide considerable gains [50-56]. Waveguide antenna was introduced in [51] as a gain-enhancement technology when used with microstrip antenna, although it only managed to gain 8.79 dB. A well-known method for increasing antenna gain is to use dividers to feed each patch of the array's antenna elements using microstrip lines [54-55] and despite having 8 and 16 elements in the array, respectively, they only provide gains of 15.50 dB and 13.76 dB. There are alternative ways to increase gain, such as by simply cutting a slot in the patch and arranging the array in a Yagi configuration [56]. Other techniques for acquiring gain by microstrip array exist, but each has drawbacks [44-45].

To address the limitations associated with existing techniques, recent research has turned towards the integration of both-sided MIC techniques [46-47]. This innovative approach involves utilizing transmission lines on both sides of the substrate, operating at microwave frequencies. Preliminary studies suggest that this technique could offer a novel solution to the low-gain problem while maintaining the antenna's compactness and simplicity in feeding technique. The proposed research aims to build upon these existing studies by designing a microstrip array antenna with multiple radiating elements and incorporating both-sided MIC techniques for feeding circuits. This approach aligns with the current trend in the literature, emphasizing the potential of both-sided MIC techniques to overcome the limitations of traditional methods and achieve enhanced gain in microstrip array antennas [47-48].

In summary, the literature review highlights the significance of addressing the low-gain issue in microstrip patch antennas and underscores the ongoing efforts to explore innovative techniques, such as both-sided MIC, to enhance their performance. The proposed research contributes to this evolving body of knowledge by integrating these findings into the design and optimization of microstrip array antennas for improved gain characteristics.

1.5 Objectives with Specific Aims and Possible Outcome

The objectives of the research are as follows:

(i) To design an array antenna with multiple radiating elements.

(ii) To design a feeding circuit using both-sided MIC technology for realizing the proposed array antenna.

(iii) To optimize the Array Antenna for achieving enhanced gain and validate its performance against recent research works.

1.5.1 Possible Outcome

By the effective use of both sides of the substrate, the possible outcome of the proposed array antenna will be most likely to have a high gain at its operating frequency with a much simpler feeding network.

1.6 Outline of Methodology/ Experimental Design

Array Antenna with multiple radiating elements and its feeding structure had been simulated and optimized using Advance Design System (ADS-2021). The simulation had been carried out through the following steps:

(i) At first simulation of a single antenna had been performed. Here the antenna characteristics had been optimized by simulation considering its impedance matching, radiation pattern and gain.

(ii) Design of a both-sided MIC feeding structure for realizing array antenna. Here, the S Parameters (S_{11}, S_{12}, S_{13} etc.) of the feeding structure had been analyzed and optimized.

(iii) Combing the radiating elements with the feeding structure for realizing the proposed array antenna. Here the characteristics (impedance matching, radiation pattern and gain) of the array antenna had been analyzed. Consequently, the gain of the array antenna had been significantly increased for using both-sided MIC and multiple radiation elements.

The research approach of this thesis is summarized in Figure 1.1.

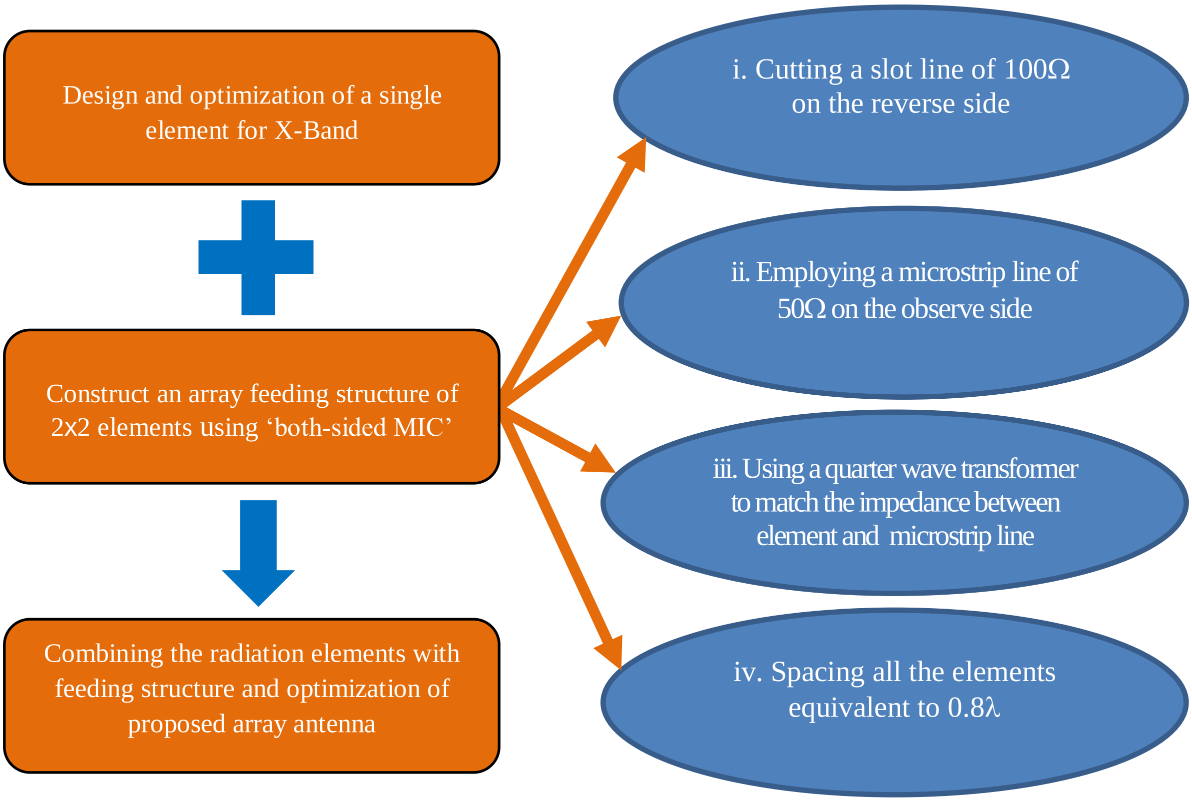


Figure 1.1: Research Approach Layout

1.7 Thesis Organization

The thesis contains six chapters which have been organized as follows:

Chapter 1 initially provides an overview of the thesis. Subsequently, it delves into the background and current status of problem in microstrip array antenna, research motivation, review of existing literature, objectives with specific aim and possible outcome and methodological approach or experimental design. Finally the chapter ends with stating the thesis organization.

Chapter 2 begins with the overview of antenna fundamentals. Then antenna basics with related antenna parameters have been discussed. Array antenna with its mathematical analysis has also been listed out and finally concluded with chapter summary.

Chapter 3 provides a detailed overview of microstrip antennas, exploring their structure, benefits, limitations, characteristics, analytical methods and feeding approaches with challenges. It introduces novel feeding technique both-sided MIC, its operation and advantages of using it in microstrip antenna. The chapter highlights the requirements for enhancing antenna gain and concludes by examining how microstrip patch array antennas are applied in real-world scenarios and finally concluded with chapter summary.

Chapter 4 focuses on microstrip array design for gain enhancement using both-sided MIC. The chapter started with an introduction, followed by a detailed design procedure of microstrip patch and feeding network and working principle of the proposed array. Thereafter result analysis has been listed out. Finally the chapter ends with a concise summary of the chapter.

Chapter 5 concentrates on the design of array for further gain enhancement by increasing the number of array elements. The chapter started with an introduction and subsequently, it outlines the design procedure, followed by result analysis. Working principle of the array of the designed microstrip array. Before concluding a comparison with recent related works has been listed out. Finally, the chapter concludes with a summary.

Chapter 6 has been completely designed to represent the concluding aspect of the research starting the summery of the finding of the thesis. Finally, the chapter concluded with mentioning the research contribution and some future scopes of work.

CHAPTER 2

ANTENNA BASICS WITH RELATED PARAMETERS AND ARRAY

2.1 Overview

An antenna is a device designed to transmit or receive electromagnetic waves, often in the form of radio frequency (RF) signals. Webster's Dictionary defines an antenna as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves". The IEEE defines the antenna or aerial as “a means for radiating or receiving radio waves.” An antenna acts as a bridge between electronic devices and the invisible world of electromagnetic waves. Antennas convert electrical signals into electromagnetic waves during transmission and reverse this process during reception. An antenna can be any shape or size. In the context of communication system antenna plays a crucial rule in facilitating the transmission and reception of information through electromagnetic waves. An antenna is a device that converts an electromagnetic signal traveling along a wire into an electromagnetic wave in free space. Antennas have a trait known as reciprocity, which indicates that regardless of whether they are transmitting or receiving, they will maintain the same properties. The majority of antennas are resonant devices that work well across a limited frequency range. Otherwise, reception and transmission will be hampered. When a signal is fed into an antenna, the antenna emits a certain type of radiation that is spread in space. Wire, aperture, microstrip, reflector, and arrays are examples of typical antenna types. Each antenna arrangement has its own radiation pattern and design factors, as well as advantages and disadvantages.

2.2 Antenna Basics

A transmission-line Thevenin equivalent of the antenna system of Figure 2.1 in the transmitting mode is shown in Figure 2.2 where the source is represented by an ideal generator, the transmission line is represented by a line with characteristic impedance Z_c, and the antenna is represented by a load Z_A [$Z_A = (R_L + R_r) + jX_A$] connected to the transmission line. The load resistance R_L is used to represent the conduction and dielectric losses associated with the antenna structure while R_r, referred to as the radiation resistance, is used to represent radiation by the antenna. The reactance X_A is used to represent the imaginary part of the impedance associated with radiation by the antenna. Under ideal conditions, energy generated by the source should be totally transferred to the radiation resistance R_r, which is used to represent radiation by the antenna. However, in a practical system there are conduction-dielectric losses due to the lossy nature of the transmission line and the antenna, as well as those due to reflections (mismatch) losses at the interface between the line and the antenna. Taking into account the internal impedance of the source and neglecting line and reflection (mismatch) losses, maximum power is delivered to the antenna under conjugate matching.

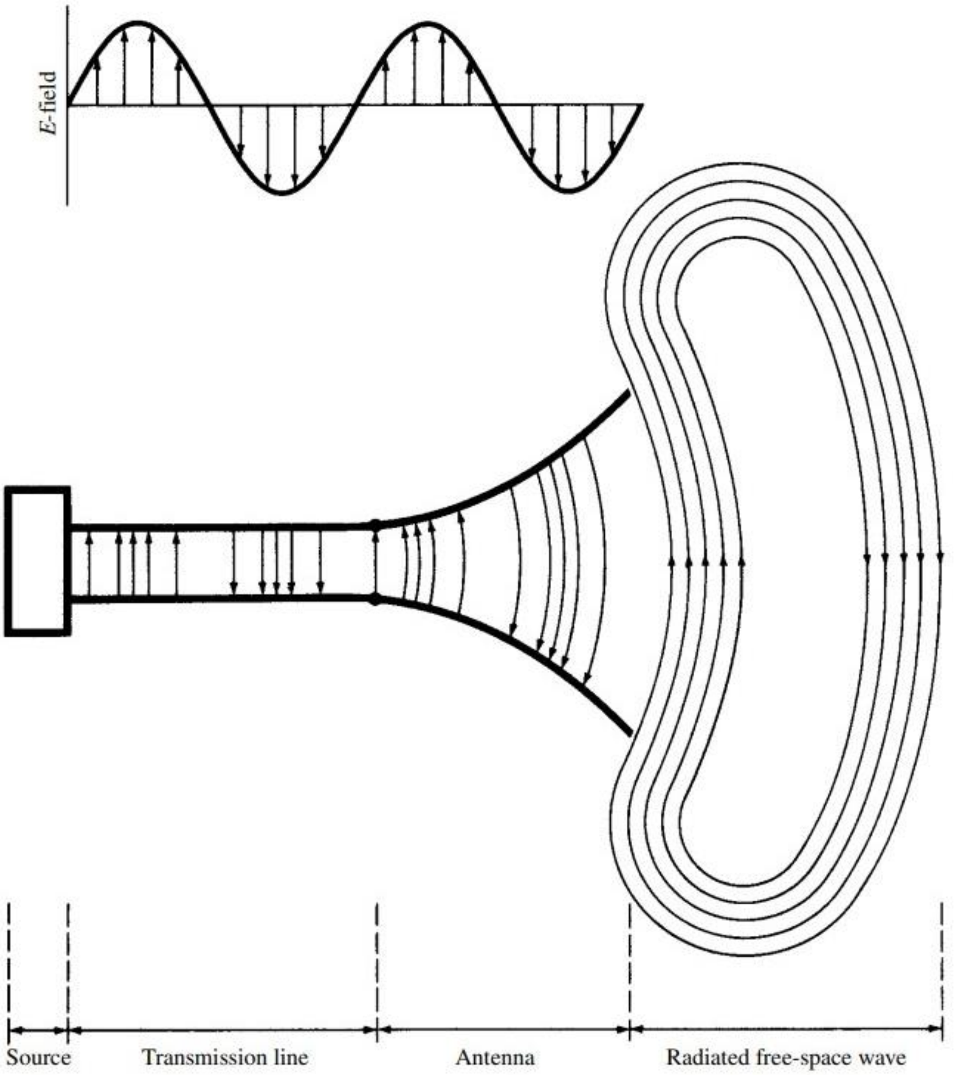


Figure 2.1: Antenna as a transition device [13]

The reflected waves from the interface create, along with the traveling waves from the source toward the antenna, constructive and destructive interference patterns, referred to as standing waves, inside the transmission line which represent pockets of energy concentrations and storage, typical of resonant devices. A typical standing wave pattern is shown dashed in Figure 2.2. If the antenna system is not properly designed, the transmission line could act to a large degree as an energy storage element instead of as a wave guiding and energy transporting device. If the maximum field intensities of the standing wave are sufficiently large, they can cause arching inside the transmission lines. The losses due to the line, antenna, and the standing waves are undesirable. The losses due to the line can be minimized by selecting low-loss lines while those of the antenna can be decreased by reducing the loss resistance represented by R_L in Figure 2.2.

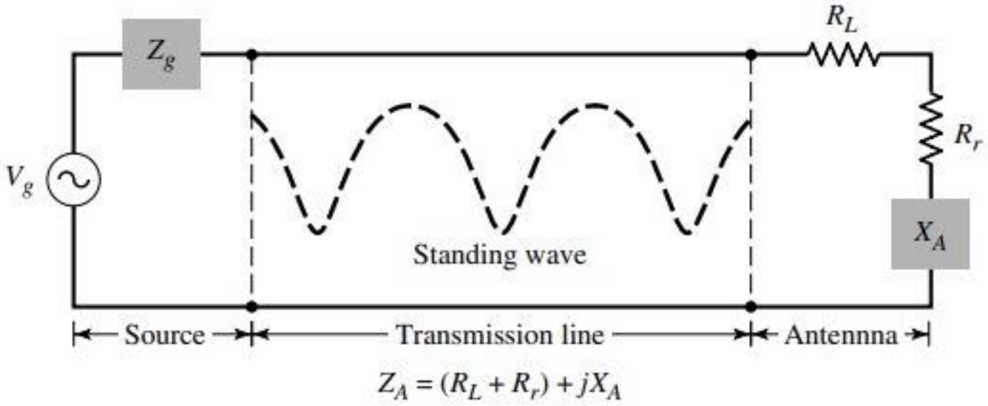


Figure 2.2: Transmission-line Thevenin equivalent of antenna in transmitting mode [13]

The standing waves can be reduced, and the energy storage capacity of the line minimized, by matching the impedance of the antenna (load) to the characteristic impedance of the line. This is the same as matching loads to transmission lines, where the load here is the antenna. An equivalent similar to that of Figure 2.2 is used to represent the antenna system in the receiving mode where the source is replaced by a receiver. All other parts of the transmission-line equivalent remain the same. The radiation resistance R_r is used to represent in the receiving mode the transfer of energy from the free-space wave to the antenna. In addition to receiving or transmitting energy, an antenna in an advanced wireless system is usually required to optimize or accentuate the radiation energy in some directions and suppress it in others. Thus the antenna must also serve as a directional device in addition to a probing device. It must then take various forms to meet the particular need at hand, and it may be a piece of conducting wire, an aperture, a patch, an assembly of elements (array), a reflector, a lens, and so forth. For wireless communication systems, the antenna is one of the most critical components. A good design of the antenna can relax system requirements and improve overall system performance.

2.3 Antenna Parameters

Some of the fundamental antenna parameters related to the thesis are described in this section.

2.3.1 Bandwidth

Bandwidth (BW) indicates the range of frequencies where the performance parameters of an antenna, namely gain, directivity, efficiency, VSWR, etc., stay within an acceptable limit, which is displayed in Figure 2.2. The bandwidth ranges from a specific frequency below the center frequency to an equal amount above the center frequency. The bandwidth is typically expressed as a ratio in broadband antennas; for instance, 100:1 means that the upper limit of bandwidth is 100 times the lower frequency.

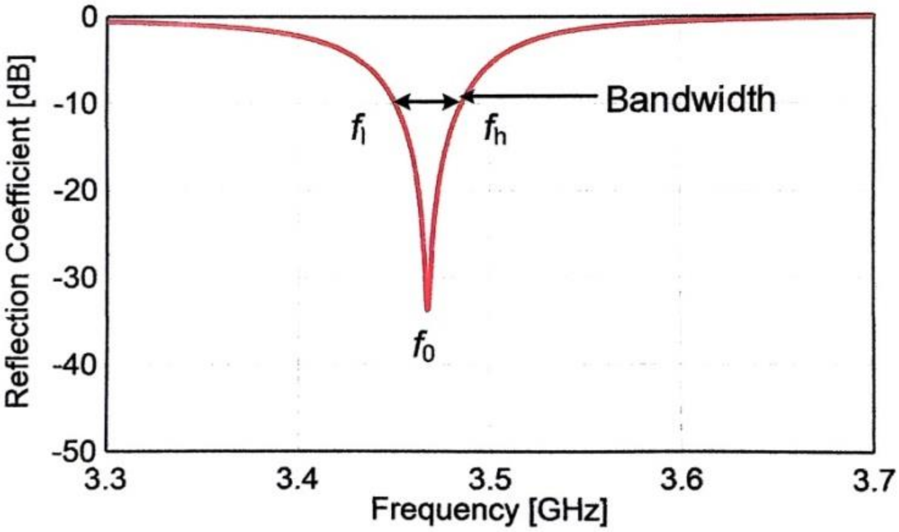


Figure 2.3: Reflection of an antenna with a 2 MHz bandwidth range

For narrowband antennas, however, it is given as a percentage. For example, a 10% bandwidth indicates the bandwidth of acceptable operation is 10% of the center frequency. As below -10 dB impedance is the acceptable range for calculating the BW of an antenna. So, from Figure 2.3, it is mentioned that the BW of the antenna is 2 MHz. Bandwidth is a measure over which an antenna can perfectly operate. It is the difference between the upper cut-off frequency (f_h) and the lower cut-off frequency (f_l) to the center frequency (f_o). It can be expressed as follows [21]:

$$\text{Bandwidth, BW} = \frac{f_{h-}\, f_l}{f_0} \tag{2.1}$$

$$\text{Where, } f_0 = \frac{f_{h-}\, f_l}{2}$$

2.3.2 Gain

Antenna gain is a parameter that is proportional to the directivity of the antenna. We already know that an antenna's directivity relates to how much energy it concentrates in one direction vs others. As a result, the antenna gain would be equal to directivity, and the antenna would be an isotropic radiator if it were 100% effective. The gain is always related to the main lobe and is specified in the direction of maximum radiation unless indicated. It is given as:

$$\text{Gain} = 4\pi \frac{\text{Radiation intensity}}{\text{Total input (accepted) power}} = 4\pi \frac{U(\theta,\varphi)}{P_{in}} \quad (2.2)$$

$$G(\theta,\varphi) = e_{cd}\left[4\pi \frac{U(\theta,\varphi)}{P_{rad}}\right] \quad (2.3)$$

$$G(\theta,\varphi) = e_{cd}\, D(\theta,\varphi) \quad (2.4)$$

Where, e_{cd} is the antenna radiation efficiency [13].

2.3.3 Directivity

In the 1983 version of the IEEE Standard Definitions of Terms for Antennas, there has been a substantive change in the definition of directivity, compared to the definition of the 1973 version. Basically the term directivity in the new 1983 version has been used to replace the term directive gain of the old 1973 version. In the new 1983 version the term directive gain has been deprecated. According to the authors of the new 1983 standards, “this change brings this standard in line with common usage among antenna engineers and with other international standards, notably those of the International Electro technical Commission (IEC).” Therefore directivity of an antenna defined as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied.” Stated more simply, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In mathematical form, it can be written as

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \quad (2.5)$$

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed [13] as

$$D_{max} = D_0 = \frac{U|\mathrm{max}}{U_0} = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}} \tag{2.6}$$

Where,
D = directivity (dimensionless)
D_0 = maximum directivity (dimensionless)
U = radiation intensity (W/unit solid angle)
U_{max} = maximum radiation intensity (W/unit solid angle)
U_0 = radiation intensity of isotropic source (W/unit solid angle)
P_{rad} = total radiated power (W)

2.3.4 Impedance Matching

An impedance matching is the process of designing or matching the antenna's input impedance (Z_L) to the RF circuitry's output impedance (Z_O), which in most circumstances is 50Ω. The antennas are types of resonant appliances which expresses superior performance whenever it is matched with respect to load. The necessities for matching of impedance are therefore:

(i) The energy radiated from the antenna in per unit area will be properly transferred if the impedance of the antenna perfectly matches the impedance of free room.

(ii) The antenna output impedance should be equal with the input impedance of the amplifier receiving antenna system for the receiving unit.

(iii) The input impedance of the transmitter antenna should be equal with the output of the transmitter devices and the impedance of the transmission line impedance (Z) that is represented in Ohms (Ω).

2.3.5 Input Impedance

The input impedance of an antenna can be portrayed by [60] as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”.

Hence the impedance of the antenna can be written as:

$$Z_{in} = R_{in} + jX_{in} \tag{2.7}$$

Where,

Z_{in} is the antenna impedance at the terminals

R_{in} is the antenna resistance at the terminals and

X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance R_r and the loss resistance R_L. The power dissipated in the loss resistance is lost as heat in the antenna itself owing to dielectric or conducting losses, whereas the power associated with radiation resistance R_r is the power actually emitted by the antenna.

2.3.6 Reflection Coefficient

The reflection coefficient is the ratio of the reflected signal to the input signal. It measures what portion of the power fed to an antenna is reflected back. It is denoted by the S_{ij} parameter, where the subscript of an S-parameter refers to the output node and the j refers to the input node. Hence, the S_{ij} indicates how much power is outputted, in other words, reflected back to the same node it was sent from. The reflection coefficient is expressed in dB, and a value of -10 dB is generally acceptable, which means that only 10% of the total power is reflected. The reflection coefficient is also defined as a ratio of reflected voltage (V^i) or current and transmitted voltage (V^j) or current and expressed by the below equation:

$$S_{ij} = \frac{V^i}{V^j} \tag{2.8}$$

2.3.7 Transmission Coefficient

The ratio of the transmitted signal to the input signal is called the transmission coefficient. As the name suggests, it measures how much of the feed power is actually transmitted to the antenna. It should be as high as possible, and when expressed in dB, the ideal value is 0 dB, i.e., all the power is transmitted with no reflection. The parameter S_{pq} is used to denote this coefficient, where p is the output and q is the input port. It measures how much power is transmitted from port q to port p.

2.3.8 Isolation Coefficient

The isolation coefficient gives an idea of how tightly coupled antennas are. If we want two antennas to be little affected by each other, then the isolation coefficient should be as low as possible because we do not want much power to be transferred between them. A standard value is -10 dB. But the lower, the better. It is also denoted by the S_{pq} parameter. Isolation between antennas can be enhanced by resorting to techniques such as:

(i) Increasing the physical separation between antennas.
(ii) Using different polarization for the antennas.

2.3.9 VSWR

VSWR, which stands for voltage standing wave ratio, is a merit figure that tells us how well the matching is between an antenna and the transmission line. It depends on the reflection coefficient but in a non-linear fashion. VSWR can be calculated with the help of the following equation:

$$\mathrm{VSWR} = \frac{1+|S_{ij}|}{1-|S_{ij}|} \tag{2.9}$$

Here, S_{ij} is the reflection coefficient.

As the reflection coefficient goes down**,** so does the VSWR. In ideal case**,** VSWR is equal to 1, when there is no reflected power. Practically, an antenna is considered good when its VSWR is between 1 and 2. However, it can vary according to bandwidth and applications.

2.3.10 Return Loss (RL)

Return loss is a figure that indicates what portion of the input power is reflected. Since the term loss is in the name, the formula is made so that it results in a positive number. The formula is as follows:

$$\mathrm{RL} = 10 \log \frac{P_{in}}{P_{ref}} \tag{2.10}$$

Here, RL is the return loss in dB, P_{in} is the incident power, and P_{ref} is the reflected power. It is worth mentioning that reflection coefficient, VSWR, and return loss, are all indicative of how much power is reflected from the antenna terminals. Based on the formula, their values may vary.

2.3.11 Antenna Efficiency

The antenna efficiency is a parameter which takes into account the number of losses at the terminals of the antenna and within the structure of the antenna. These losses are given by [60] as:

- (i) Reflections because of mismatch between the transmitter and the antenna
- (ii) I^2R losses (conduction and dielectric)

Hence the total antenna efficiency can be written as:

$$e_t = e_r e_c e_d \tag{2.11}$$

Where,

e_t = total antenna efficiency

$e_r = (1 - |\Gamma|^2)$ = reflection (mismatch) efficiency

e_c = conduction efficiency

e_d = dielectric efficiency

Since e_c and e_d are difficult to separate, they are lumped together to form the e_{cd} efficiency which is given as:

$$e_{cd} = e_c e_d = \frac{R_r}{R_r + R_L} \tag{2.12}$$

e_{cd} is called as the antenna radiation efficiency and is defined as the ratio of the power delivered to the radiation resistance (R_r) to the power delivered to R_r and R_L (load resistance).

2.3.12 S-Parameters

S-parameters, or scattering parameters, are a set of mathematical parameters widely used in the field of RF (Radio Frequency) and microwave engineering to characterize the behavior of linear electrical networks, such as antennas, amplifiers, filters, and transmission lines. S-parameters describe how electrical signals are transmitted and reflected at different ports in a network when electromagnetic waves or electrical signals are incident upon it. S-parameters are typically represented as a matrix, and for a two-port network, there are four S-parameters, often denoted as S_{11}, S_{21}, S_{12} and S_{22}. The scattering parameters are represented by S-parameters. As a P-port network where V_P^+ is the incident voltage wave of port n and V_P^- is the reflected voltage wave of port P.

The scattering matrix [S] will be [18] the following equation:

$$\begin{bmatrix} V_1^- \\ V_2^- \\ \vdots \\ V_P^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1P} \\ S_{21} & S_{22} & \vdots & S_{2P} \\ \vdots & \vdots & \ddots & \vdots \\ S_{P1} & S_{P2} & \cdots & S_{PN} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \\ \vdots \\ V_P^+ \end{bmatrix} \tag{2.13}$$

or,

$$[V^-] = [S][V^+] \tag{2.14}$$

2.3.13 Quarter wavelength Impedance Transformer

A quarter-wavelength impedance transformer is a transmission line or structure designed to match the impedance of a load to specific characteristic impedance at a certain frequency by exploiting the quarter-wavelength property. In the context of microstrip antennas, a quarter-wave transformer typically consists of a section of transmission line whose electrical length is one-fourth of the wavelength at the operating frequency. The quarter-wave transformer operates based on the principle that when the electrical length of a transmission line is one-quarter of the wavelength, the load impedance at one end appears transformed to different impedance at the other end. The transformation is such `that the impedance seen at the load end is effectively inverted, providing a matching condition. For microstrip antennas, a quarter-wave transformer is often used to match the relatively high impedance of the microstrip transmission line to the lower impedance of the radiating element (such as a patch). This helps to minimize signal reflections and ensures efficient power transfer.

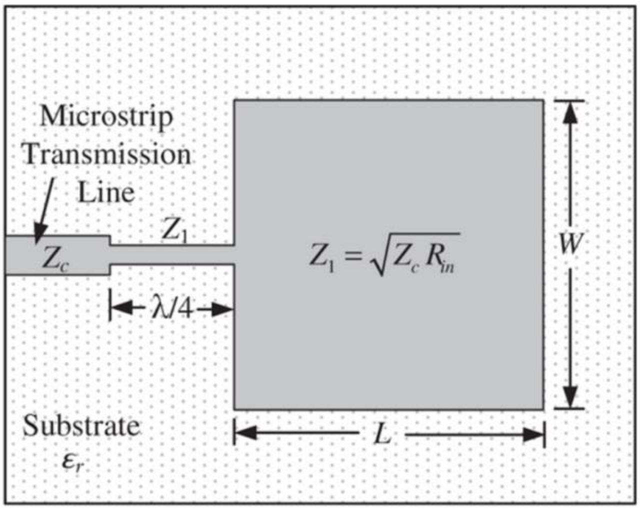


Figure 2.4: Quarter wavelength impedance matching circuit

2.4 Array Antenna

An array antenna, also known as an antenna array, is a configuration of multiple antennas working together as a single unit. These antennas are arranged in a specific geometric pattern to achieve desired characteristics, such as increased gain, beam steering, or pattern shaping. Array antennas are commonly used in various communication systems, radar systems, and other applications where enhanced performance is required. The gain enhancement in an array antenna is achieved through the constructive interference of signals from individual antennas. When multiple antennas are closely spaced and properly aligned, the signals they radiate can combine in a way that reinforces or adds up their amplitudes. This phenomenon is known as constructive interference, and it leads to a more focused and directional radiation pattern with enhanced gain.

2.4.1 Mathematical Analysis for Array

The simplest and one of the most practical arrays are formed by placing the elements along a line. To simplify the presentation and give a better physical interpretation of the techniques, a two-element array will first be considered. The analysis of an N-element array will then follow.

2.4.1.1 Two-Element Array

Let us assume that the antenna under investigation is an array of two infinitesimal horizontal dipoles positioned along the z-axis, as shown in Figure 2.5(a). The total field radiated by the two elements, assuming no coupling between the elements, is equal to the sum of the two and in the y-z plane it is given [13] by

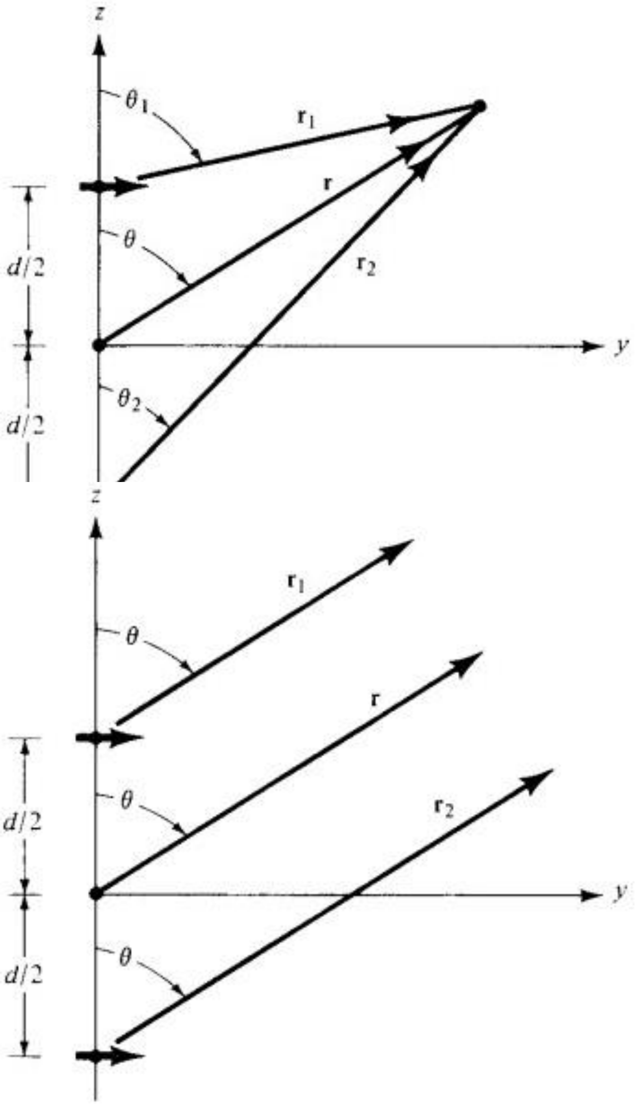
$$E_t = E_1 + E_2 = \hat{a}_\theta j\eta \frac{kI_0 l}{4\pi}\left\{\frac{e^{-j\left[kr_1 - \left(\frac{\beta}{2}\right)\right]}}{r_1}\cos\theta_1 + \frac{e^{-j\left[kr_2 - \left(\frac{\beta}{2}\right)\right]}}{r_2}\cos\theta_2\right\} \tag{2.15}$$

Where, β is the difference in phase excitation between the elements. The magnitude excitation of the radiators is identical. Assuming far-field observations and referring to Figure 2.5(b),

$$\theta_1 \simeq E_1 \simeq \theta \tag{2.16}$$

$$\left.\begin{aligned} r_1 &\simeq r - \frac{d}{2}\cos\theta \\ r_2 &\simeq r + \frac{d}{2}\cos\theta \end{aligned}\right\} \text{for phase variations} \tag{2.17}$$

$$r_1 \simeq r_2 \simeq r \text{ for amplitude variations} \tag{2.18}$$



(b) Far-field observations

Figure 2.5: Geometry of a two-element array positioned along the z-axis

It is apparent from that the total field of the array is equal to the field of a single element positioned at the origin multiplied by a factor which is widely referred to as the array factor. Thus for the two-element array of constant amplitude, the array factor is given by which in normalized form can be written as

$$(AF)_n = \cos\left[\frac{1}{2}\left(kd\cos\theta + \beta\right)\right] \tag{2.19}$$

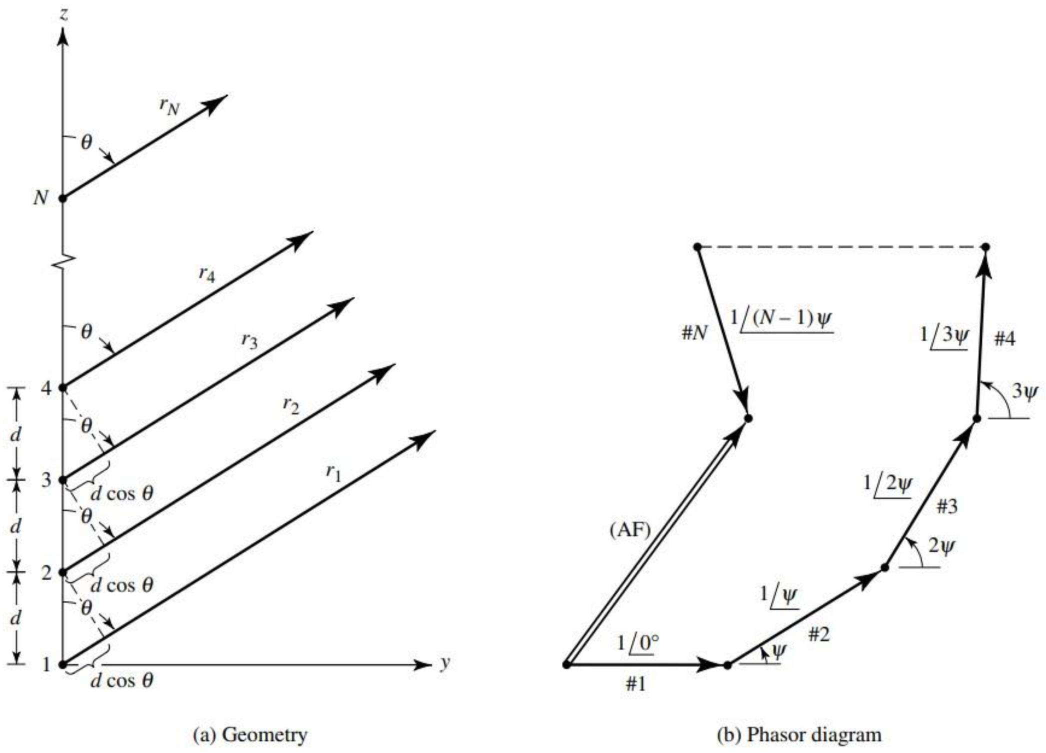
The array factor is a function of the geometry of the array and the excitation phase. By varying the separation d and/or the phase β between the elements, the characteristics of the array factor and of the total field of the array can be controlled. It has been illustrated that the far-zone field of a uniform two-element array of identical elements is equal to the product of the field of a single element, at a selected reference point (usually the origin), and the array factor of that array [13]. That is,

$$\text{E(Total)} = [\text{E(Single element at reference point)}] \times [\text{Array factor}] \qquad (2.20)$$

This is referred to as pattern multiplication for arrays of identical elements. Although it has been illustrated only for an array of two elements, each of identical magnitude, it is also valid for arrays with any number of identical elements which do not necessarily have identical magnitudes, phases, and/or spacing's between them. Each array has its own array factor. The array factor, in general, is a function of the number of elements, their geometrical arrangement, their relative magnitudes, their relative phases, and their spacing's. The array factor will be of simpler form if the elements have identical amplitudes, phases, and spacing's. Since the array factor does not depend on the directional characteristics of the radiating elements themselves, it can be formulated by replacing the actual elements with isotropic (point) sources. Once the array factor has been derived using the point-source array, the total field of the actual array is obtained by the use of (2.20).

2.4.1.2 N-Element Linear Array

Now that the arraying of elements has been introduced and it was illustrated by the two-element array, let us generalize the method to include N elements. Referring to the geometry of Figure 2.6(a), let us assume that all the elements have identical amplitudes but each succeeding element has a β progressive phase lead current excitation relative to the preceding one (β represents the phase by which the current in each element leads the current of the preceding element). An array of identical elements all of identical magnitude and each with a progressive phase are referred to as a uniform array. The array factor can be obtained by considering the elements to be point sources. If the actual elements are not isotropic sources, the total field can be formed by multiplying the array factor of the isotropic sources by the field of a single element. This is the pattern multiplication rule of (2.20), and it applies only for arrays of identical elements.



(a) Geometry

(b) Phasor diagram

Figure 2.6: Far-field geometry and phasor diagram of N-element array of isotropic sources positioned along the z-axis

The array factor is given [13] by

$$\mathrm{AF} = 1 + e^{+j(kd\cos\theta+\beta)} + e^{+j2(kd\cos\theta+\beta)} + \cdots + e^{j(N-1)(kd\cos\theta+\beta)}$$

$$\mathrm{AF} = \sum_{n=1}^{N} e^{j(n-1)(kd\cos\theta+\beta)} \tag{2.21}$$

which can be written as

$$\mathrm{AF} = \sum_{n=1}^{N} e^{j(n-1)\psi} \tag{2.22}$$

$$\text{Where } \psi = kd\cos\theta + \beta \tag{2.22a}$$

Since the total array factor for the uniform array is a summation of exponentials, it can be represented by the vector sum of N phasors each of unit amplitude and progressive phase ψ relative to the previous one. Graphically this is illustrated by the phasor diagram in Figure 2.6(b). It is apparent from the phasor diagram that the amplitude and phase of the AF can be controlled in uniform arrays by properly selecting the relative phase ψ between the elements; in non-uniform arrays, the amplitude as well as the phase can be used to control the formation and distribution of the total array factor.

2.5 Summary

In this chapter, presenting an overview of antenna and its significance in wireless communication system with antenna basics, different related antenna parameters have been discussed. The goal of this research is to design and optimization of microstip array antenna for gain enhancement. So the mathematical representation for the array antenna has also been discussed for 2-Elements array and subsequently for N-Element array.

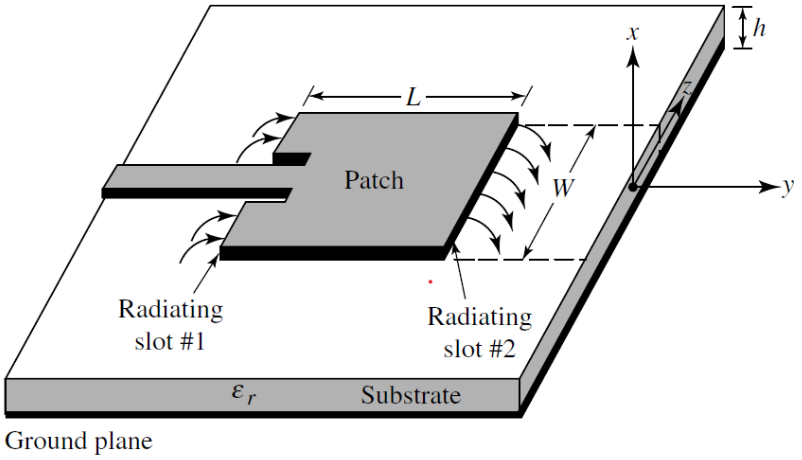
CHAPTER 3
MICROSTRIP ANTENNA

3.1 Overview

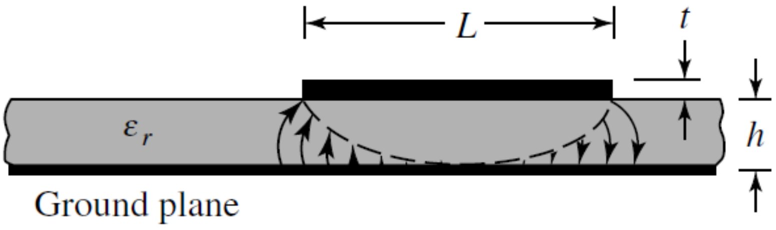
A Microstrip Antenna is a type of radio-frequency antenna that consists of a metallic strip (usually made of a conducting material such as copper) placed on top of a dielectric substrate, which is typically a thin layer of material like fiberglass or ceramic. In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required [13]. Presently there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet these requirements, microstrip antennas [16-17] can be used. These antennas are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versa- tile in terms of resonant frequency, polarization, pattern, and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern can be designed.

3.2 Basic Construction and Antenna Geometry

The basic construction of a microstrip antenna involves the following key components such as Radiating Patch, Ground Plane and Dielectric Substrate shown in figure:



(a) Top View



(b) Side View

Figure 3.1: Basic Construction of Microstrip Antenna [13]

3.2.1 Radiating Patch

The central element of a microstrip antenna is the radiating patch, which is typically a flat, conductive structure. The shape and dimensions of the patch are crucial in determining the resonant frequency and radiation characteristics of the antenna. Common shapes include rectangular, square, circular, or elliptical patches. The radiating patch is typically made of a conductive material with good electrical conductivity, such as copper or aluminum. Copper is a popular choice due to its excellent conductivity and ease of manufacturing.

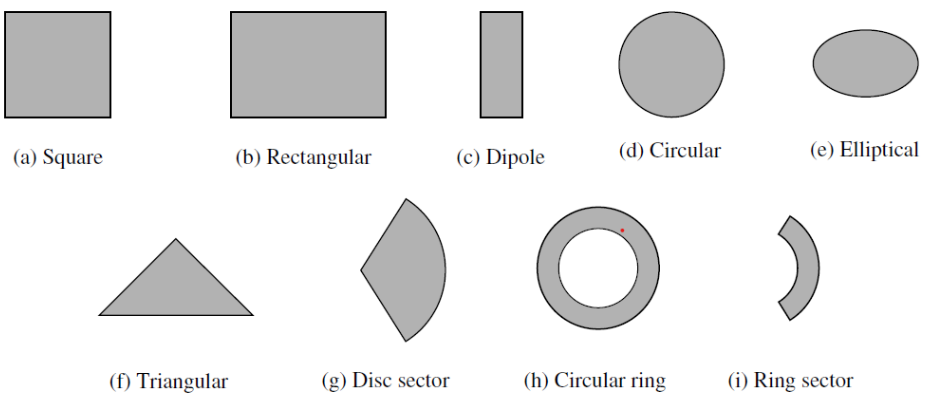


Figure 3.2 Shapes of Microstrip Patch Elements [13]

3.2.2 Ground Plane

On one side of the dielectric substrate, there is a ground plane that acts as a reflective surface for the radiating patch. The ground plane is also conductive and is essential for achieving the desired radiation pattern. It is typically larger than the radiating patch to ensure effective reflection (Figure 3.1).

3.2.3 Dielectric Substrate

The radiating patch and ground plane are separated by a dielectric substrate, which is a non-conductive material. This substrate provides mechanical support to the antenna structure and influences its electrical properties. The choice of substrate material is crucial in determining the antenna's performance parameters, such as impedance matching, bandwidth, and efficiency. The dielectric substrate can be made from various materials, each with its own set of characteristics. Common substrate materials include fiberglass-reinforced epoxy (FR4), Rogers RO4003C, Polytetrafluoroethylene (PTFE), Arlon Clad Laminates, Polyimide and Teflon etc. The dielectric constant and loss tangent of the substrate material significantly influence the antenna's electrical performance. Understanding the fundamental components and construction of microstrip antennas lays the foundation for exploring their operational principles and applications in wireless communication systems (Figure 3.1).

3.3 Advantages of Microstrip Antenna

The advantages [1-2] of microstrip patch antennas are:

- (i) Planar, this can also be made conformal to a shaped surface.
- (ii) Low profile and minimum radar cross-section.
- (iii) Rugged and can be manufactured by printed circuit technology.
- (iv) Integrable with circuit elements.
- (v) Can be made suitable for dual polarization operations.

3.4 Limitations of Microstrip Antenna

There are several disadvantages [1-2] associated with microstrip patch antennas:

- (i) Low gain and radiation efficiency.
- (ii) Low Bandwidth.
- (iii) Low power handling Capability.
- (iv) Complex feeding technique for array.

3.5 Basic Characteristics

Microstrip antennas, as shown in Figure 3.1(a), consist of a very thin ($t << \lambda_0$, where λ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wave-length ($h << \lambda_0$, usually $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$) above a ground plane. The microstrip patch is designed so its pattern maximum is normal to the patch (broadside radiator). This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate), as shown in Figure 3.1(a), [32].

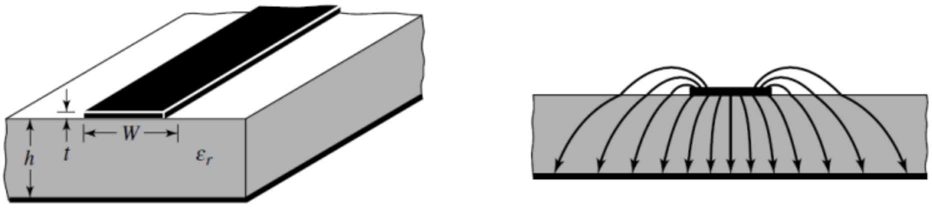
There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.0 \leq \varepsilon_r \leq 12$. The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size [18]. Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element sizes; however, because of their greater losses, they are less efficient and have relatively smaller bandwidths [18].

3.6 Methods of Analysis

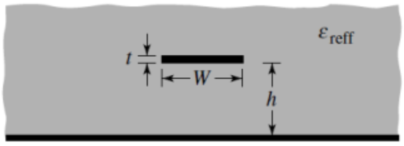
There are many methods of analysis for microstrip antennas. The most popular models are the transmission-line method [15-17].

3.6.1 Fringing Effect

The fringing effect in microstrip antennas refers to the phenomenon where electric field lines extend beyond the physical edges of the radiating patch. This effect is a consequence of the electric field's interaction with the surrounding dielectric substrate and the air. As the electric field lines extend into the surrounding medium, they contribute to the overall electromagnetic field of the antenna. For a microstrip line shown in Figure 3.3(a), typical electric field lines are shown in Figure 3.3(b). This is a nonhomogeneous line of two dielectrics; typically the substrate and air. As can be seen, most of the electric field lines reside in the substrate and parts of some lines exist in air. As $W/h \gg 1$ and $\varepsilon_r >> 1$, the electric field lines concentrate mostly in the substrate. Fringing in this case makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line.



(a) Microstrip line (b) Electric field lines



(c) Effective dielectric constant

Figure 3.3: Microstrip line & its electric field lines and effective dielectric constant geometry

The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that the line of Figure 3.3(c) has identical electrical characteristics, particularly propagation constant, as the actual line of Figure 3.3(a). For a line with air above the substrate, the effective dielectric constant has values in the range of $1 < \varepsilon_{\text{reff}} < \varepsilon_{\text{r}}$.

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they are given by [19]

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_{\text{r}}+1}{2} + \frac{\varepsilon_{\text{r}}-1}{2}\left[1 + 12\,\frac{\text{h}}{\text{W}}\right]^{-1/2} \quad \text{When W/h>1} \qquad (3.1)$$

3.6.2 Effective Length, Resonant Frequency, and Effective Width

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions [18].

- **(i)** **Effective Length**: The effective length of a microstrip antenna refers to the electrical length of the radiating element, which determines its resonance and radiation pattern. It is typically shorter than the physical length due to the effect of the dielectric substrate and other factors.
- **(ii)** **Resonant Frequency**: Resonant frequency in a microstrip antenna is the frequency at which it efficiently radiates electromagnetic waves. It occurs

when the electrical length of the antenna matches the wavelength of the electromagnetic signal it is designed to transmit or receive.

(iii) **Effective Width**: In a microstrip antenna, the effective width refers to the width of the radiating patch or element that contributes significantly to the radiation pattern and impedance matching. It accounts for the dielectric properties of the substrate and the design parameters of the antenna.

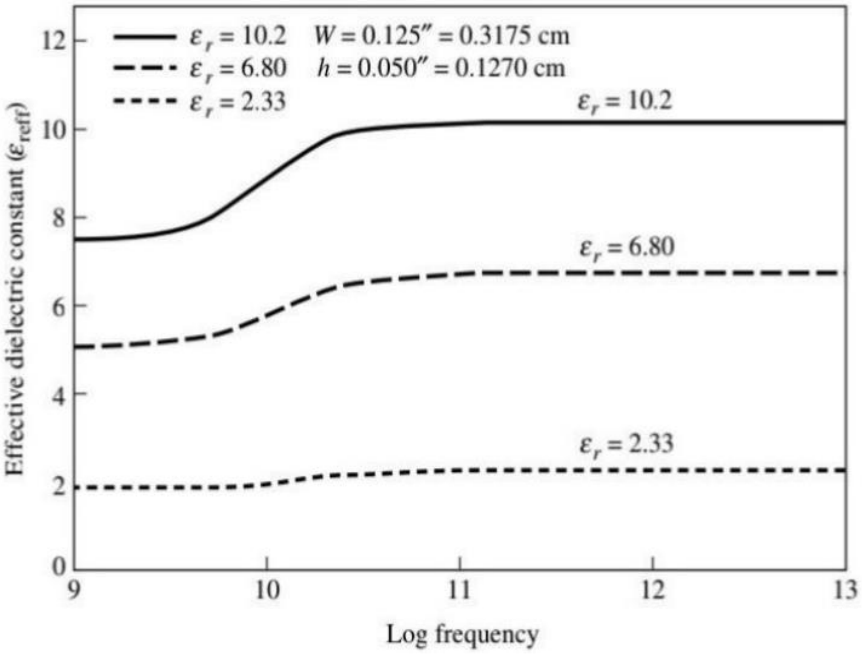
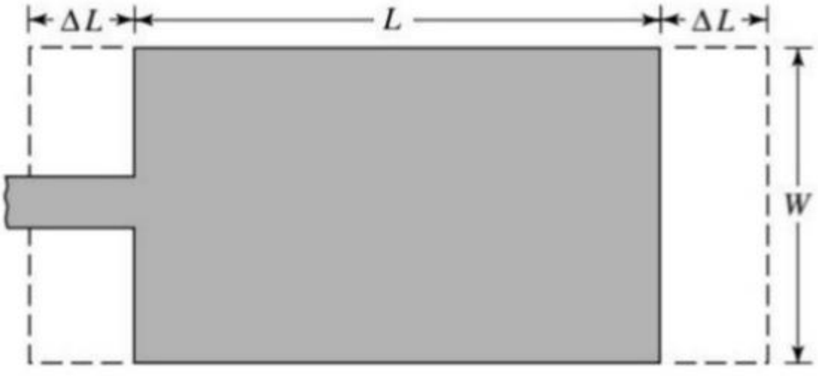


Figure 3.4: Effective dielectric constant versus frequency for typical substrates [13]

For the principal E-plane (xy-plane), this is demonstrated in Figure 3.5 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant ε_{reff} and the width-to-height ratio (W/h).



(a) Top view

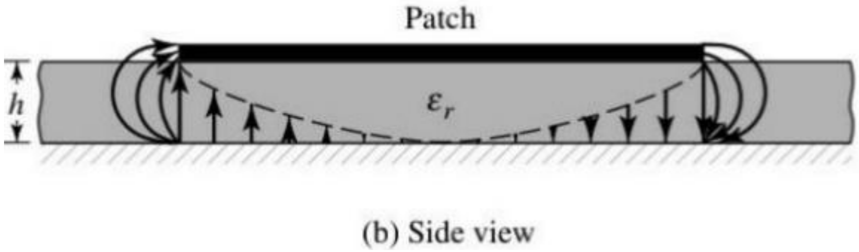


Figure 3.5: Physical and effective lengths of rectangular microstrip patch

A very popular and practical approximate relation for the normalized extension of the length is [20]

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h}+0.8\right)} \tag{3.2}$$

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now (L = λ/2 for dominant TM_{010} mode with no fringing)

$$L_{eff} = L + 2\Delta L \tag{3.3}$$

The actual length of the patch can now be determined by solving (3.7) L, or

$$L = \frac{1}{2f_r\,\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \tag{3.4}$$

For an efficient radiator, a practical width that leads to good radiation efficiencies is

$$W = \frac{1}{2f_r\,\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{3.5}$$

For the dominant TM_{010} mode, the resonant frequency of the microstrip antenna is a function of its length. Usually it is given by

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\epsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \tag{3.6}$$

where v_0 is the speed of light in free space. Since (3.6) does not account for fringing, it must be modified to include edge effects and should be computed using

$$(f_{rc})_{010} = \frac{1}{2L_{eff}\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} = \frac{1}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\epsilon_0}} \quad (3.7)$$

$$= q\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\epsilon_0}} = q\frac{v_0}{2L\sqrt{\varepsilon_r}} \quad (3.7)$$

Where,

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \quad (3.7a)$$

The q factor is referred to as the fringe factor (length reduction factor). As the substrate height increases, fringing also increases and leads to larger separations between the radiating edges and lower resonant frequencies.

3.6.3 Conductance

Each radiating slot is represented by a parallel equivalent admittance Y (with conductance G and susceptance B). The slots are labeled as #1 and #2. The equivalent admittance of slot #1, based on an infinitely wide, uniform slot and it is given by.

$$Y_1 = G_1 + jB_1 \quad (3.8)$$

Where for a slot of finite width W

$$G_1 = \frac{W}{120\,\lambda_0}\left[1 - \frac{1}{24}(k_0h)^2\right];\ \frac{h}{\lambda_0} < \frac{1}{10} \quad (3.8a)$$

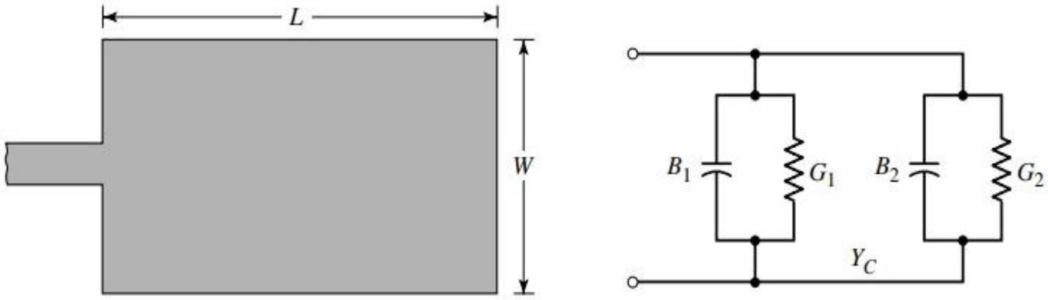
$$B_1 = \frac{W}{120\,\lambda_0}\left[1 - 0.606\ln(k_0h)\right];\ \frac{h}{\lambda_0} < \frac{1}{10} \quad (3.8b)$$

Since slot #2 is identical to slot #1, its equivalent admittance is

$$Y_2 = Y_1, G_2 = G_1, B_2 = B_1 \quad (3.9)$$

The conductance of a single slot can also be obtained by using the field expression derived by the cavity model. In general, the conductance is defined as

$$G_1 = \frac{2P_{rad}}{|V_0|^2} \quad (3.10)$$



(a) Rectangular patch (b) Transmission model equivalent

Figure 3.6: Rectangular microstrip patch and its equivalent circuit transmission-line model

Using the electric field of (3.10), the radiated power is written as

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_0} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta} \right]^2 \sin^3\theta d\theta \tag{3.11}$$

Therefore the conductance of (3.10) can be expressed as

$$G_1 = \frac{I_1}{120\pi^2} \tag{3.12}$$

Where,

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta} \right]^2 \sin^3\theta d\theta$$

$$= -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X} \tag{3.12a}$$

$$X = k_0 W \tag{3.12b}$$

Asymptotic values of (3.12) and (3.12a) are

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 & ; \quad W \ll \lambda_0 \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right) & ; \quad W \gg \lambda_0 \end{cases} \tag{3.13}$$

The values of (3.13) for $W \gg \lambda_0$ are identical to those given by (3.8a) for $h \ll \lambda_0$. A plot of as a function of W/λ_0 is shown in Figure 3.7.

3.6.4 Resonant Input Resistance & Characteristics Impedance of Feed Line

The total admittance at slot #1 (input admittance) is obtained by transferring the admittance of slot #2 from the output terminals to input terminals using the admittance transformation equation of transmission lines [15], [33], [19]. Ideally the two slots should be separated by λ/2 where λ is the wavelength in the dielectric (substrate). However, because of fringing the length of the patch is electrically longer than the actual length. Therefore the actual separation of the two slots is slightly less than λ/2. If the reduction of the length is properly chosen using (3.2) (typically $0.48\lambda < L < 0.49\lambda$), the transformed admittance of slot #2 becomes

$$\tilde{Y}_2 = \tilde{G}_2 + j\tilde{B}_2 = G_1 - jB_1 \tag{3.14}$$

or

$$\tilde{G}_2 = G_1 \tag{3.14a}$$

$$\tilde{B}_2 = -B_1 \tag{3.14b}$$

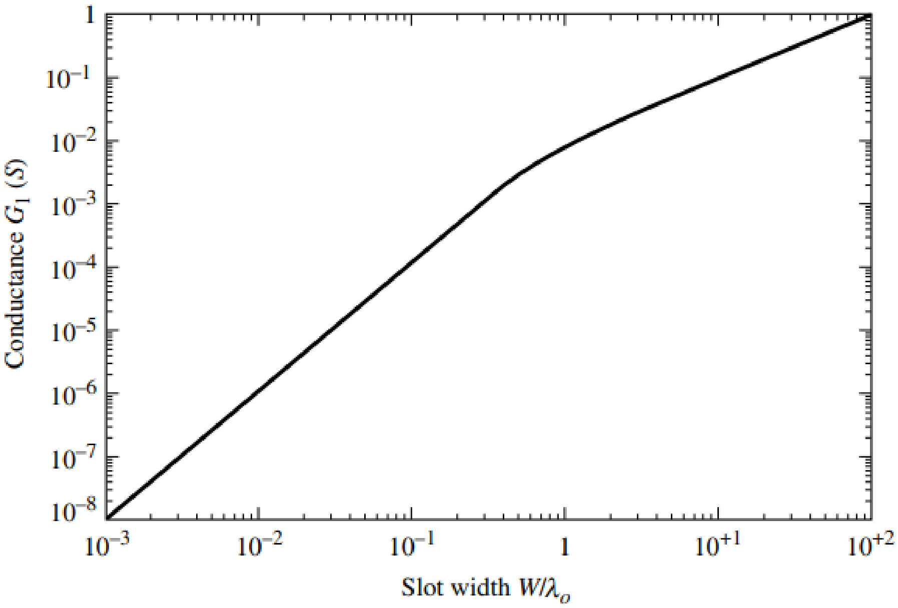


Figure 3.7: Slot conductance's as a function of slot width [13]

Therefore the total resonant input admittance is real and is given by

$$Y_{in} = Y_1 + \tilde{Y}_2 = 2G_1 \tag{3.15}$$

Since the total input admittance is real, the resonant input impedance is also real, or

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \tag{3.16}$$

The resonant input resistance, as given by (3.16), does not take into account mutual effects between the slots. This can be accomplished by modifying (3.16) to

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \tag{3.17}$$

Where the plus (+) sign is used for modes with odd (anti symmetric) resonant voltage distribution beneath the patch and between the slots while the minus (−) sign is used for modes with even (symmetric) resonant voltage distribution. The mutual conductance is defined, in terms of the far-zone fields, as

$$G_{12} = \frac{1}{|V_0|^2} \mathrm{Re} \int_s \left(E_1 \times H_2^*\right) . ds \tag{3.18}$$

Where E_1 is the electric field radiated by slot #1, H_2 is the magnetic fields radiated by slot #2, V_0 is the voltage across the slot, and the integration is performed over a sphere of large radius. The resonant input resistance, as calculated by the patch antenna using a microstrip line feed whose characteristic impedance is given by [19]

$$Z_c = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{reff}}} \ln\left[\dfrac{8h}{W_0} + \dfrac{W_0}{4h}\right] & ; \ \dfrac{W_0}{h} \leq 1 \\ \dfrac{120\pi}{\sqrt{\varepsilon_{reff}\left[\dfrac{W_0}{h} + 1.393 + 0.667 \ln\left(\dfrac{W_0}{h} + 1.444\right)\right]}} & ; \ \dfrac{W_0}{h} > 1 \end{cases} \tag{3.19}$$

Where W_0 is the width of the microstrip line. Using modal expansion analysis, the input resistance is given approximately by [34], [15]

$$R_{in}(y = y_0) = \frac{1}{2\,(G_1 \pm G_{12})}\left[\cos^2\left(\frac{\pi}{L} y_0\right) + \frac{G_1^2 + B_1^2}{Y_c^2} \sin^2\left(\frac{\pi}{L} y_0\right) - \frac{B_1}{Y_c} \sin\left(\frac{2\pi}{L} y_0\right)\right] \tag{3.20}$$

To radiate maximum power $Z_c = R_{in}$ is to satisfy. At the edge of the patch R_{in} is maximum and it gradually decreases inside and is equal to zero at the center of the patch.

3.6.5 Design Procedure

Based on the simplified formulation that has been described; a design procedure is outlined which lead to practical designs of rectangular microstrip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate (ε_r), the resonant frequency (f_r), and the height of the substrate, h. The procedure is as follows:

Specify: Following information need to be specified for designing a particular antenna:

(i) Resonant frequency (f_r);

(ii) Dielectric constant of substrate (ε_r)

(iii) Hight of the substrate, h_s

Determine: W & L

For an efficient radiator, a practical width that leads to good radiation efficiencies.

$$\mathrm{w} = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (3.21)$$

Where υ_o is the free-space velocity of light.

Determine the effective dielectric constant of the microstip antenna using (3.1)

Once W is found using (3.21) determines the extension of length ΔL using (3.2)

The actual length of the patch can now be determined by solving (3.7) for L, or

$$\mathrm{L} = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta\mathrm{L} \qquad (3.22)$$

The precise or absolute value will not be provided to the mathematical design. The result will be a closer value. For design and optimisation using simulation tools, this is useful.

3.7 Feeding Methods of Microstrip Antenna

A feed line is used to excite to radiate by direct or indirect contact with the patch. The feed transports electromagnetic energy from the source to the patched area. Some of this energy escapes the patch's boundaries and is radiated into space. A multitude of ways are used to feed the signal in microstrip patch antennas. Feeding techniques are divided into two categories: contacting and non-contacting [22]. In the contacting method, the input radio frequency power is fed directly to the patch by a connecting element, and in the non-contacting scheme, electromagnetic field coupling is done to transfer the power between the microstrip line and the radiating patch. The four most popular feeding techniques are the co-axial feed, microstrip line feed, aperture-coupled feed, and proximity-coupled feed. Different feeding methods influence antenna properties such as bandwidth, radiation pattern, polarization, gain and impedance, etc.

3.7.1 Microstrip Line Feed

It is a feeding technology in which the conducting microstrip feed line is directly attached to the microstrip patch. The microstrip line feed is shown in Figure 3.8. The feed line's dimensions are different from those of a microstrip patch. It is simple to manufacture proficient feeding [23]. Simple and easy to implement but may suffer from radiation losses and impedance mismatch.

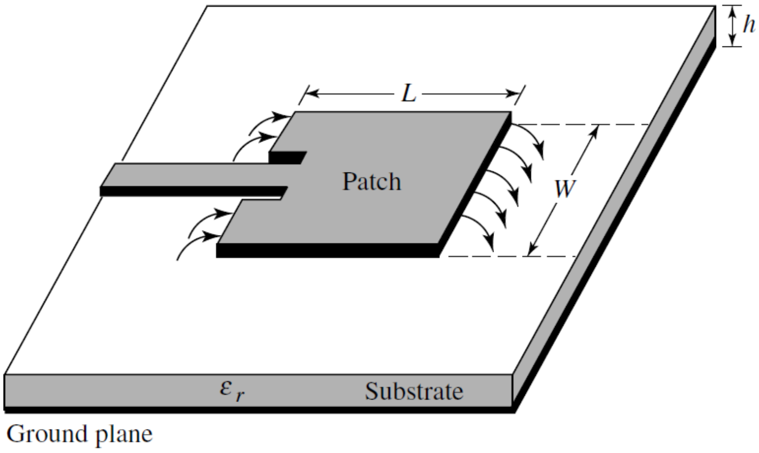


Figure 3.8: Microstrip Line Feed [13]

3.7.2 Co-axial Probe Feed

A coaxial cable is used to feed the microstrip antenna. The outer conductor is usually connected to the ground plane; while the center conductor is connected to the radiating patch the benefits of the coaxial feeding method include efficient feeding, easy manufacture, and less spurious radiation [23]. But appropriate selection of feeding point for matching is a difficult task. The coaxial probe feed is shown in Figure 3.9.

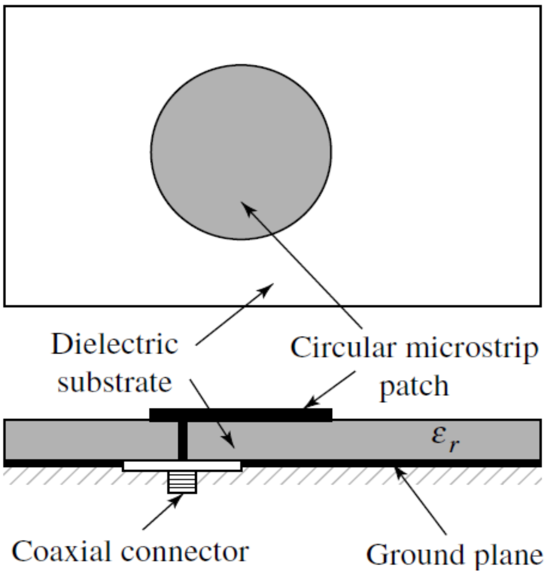
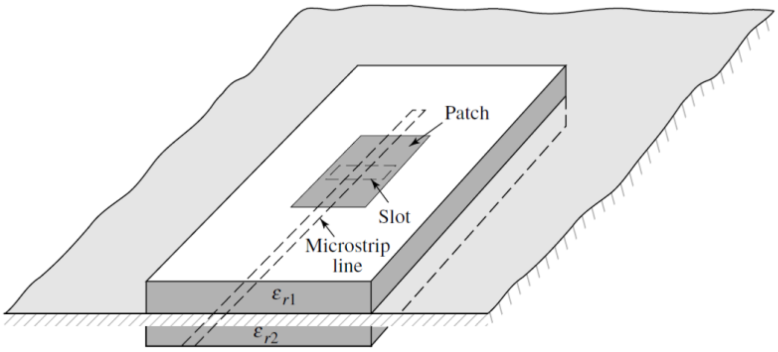


Figure 3.9: Co-axial Probe Feed [13]

3.7.3 Aperture-Coupled Feed

This feed contains two distinct substrates that are separated from one another by a ground plane. Through a slot in the ground plane, the microstrip patch and feed lines are coupled in this approach. The benefits of the aperture-coupled feeding approach include minimization of interference and pure polarization. Complex design and fabrication [24]. The aperture-coupled feed is shown in Figure 3.10.

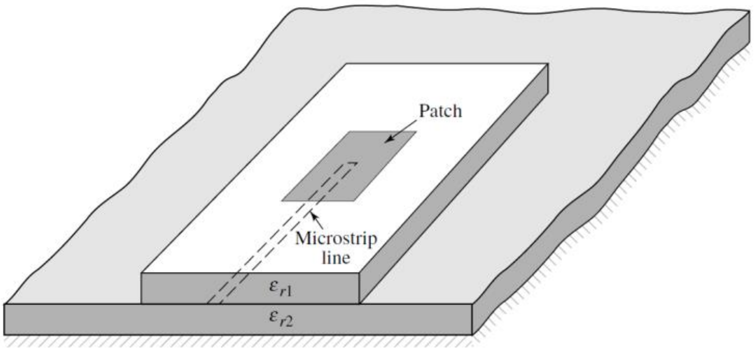


(c) Aperture-coupled feed

Figure 3.10: Aperture-Coupled Feed [13]

3.7.4 Proximity-Coupled Feed

In this feeding method the feed line is placed in close proximity to the radiating patch without direct contact. Energy is coupled electromagnetically between the feed line and the patch. It offers the widest bandwidth and prevents erroneous radiation [25]. The proximity-coupled feed is shown in Figure 3.11.



(d) Proximity-coupled feed

Figure 3.11: Proximity-Coupled Feed [13]

3.8 Difficulties in Feeding Technique of Microstrip Antenna

The feeding technique in microstrip antennas can present several challenges that designers need to address for optimal performance. Some of the difficulties in feeding techniques of microstrip antennas are discussed below.

3.8.1 Impedance Matching

Achieving proper impedance matching between the microstrip antenna and the feeding network is a critical challenge. Mismatched impedance can result in reflections, reduced power transfer, and degraded overall antenna performance.

3.8.2 Radiation Pattern Distortion

The feeding technique can influence the radiation pattern of the microstrip antenna. Careful design is needed to minimize distortions and ensure that the antenna meets the desired radiation characteristics.

3.8.3 Feed Point Placement

The placement of the feeding structure can impact the radiation pattern and impedance matching. Selecting the right location for the feed point is crucial for achieving the desired antenna performance.

3.8.4 Cross-Polarization and Side Lobes

Improper feeding techniques can lead to unwanted effects such as cross-polarization and the generation of side lobes in the radiation pattern. These effects can degrade the antenna's performance and affect its suitability for specific applications.

3.8.5 Power Handling and Efficiency

Efficient power transfer from the feed line to the radiating element is crucial. Issues such as power loss in the feeding network or inefficient coupling can reduce the overall efficiency of the microstrip antenna.

3.8.6 Non-Uniform Current Distribution

Achieving a uniform current distribution on the radiating patch can be difficult, especially when using certain feeding techniques. Non-uniform current distribution can result in uneven radiation and impedance characteristics.

3.9 Both-Sided MIC Technique

Microwave Integrated Circuits (MIC) are a class of electronic circuits designed to operate at microwave frequencies. These circuits leverage the advantages of miniaturization and integration, allowing for compact and efficient solutions in microwave systems. In the realm of antenna design, MIC technology provides a versatile platform for enhancing antenna performance, enabling sophisticated control over parameters such as impedance matching, power handling, and noise figure. Microwave integrated circuits (MICs) are crucial parts in microwave and millimeter waveband electronics. The main transmission lines in most MICs are microstrip lines. Coplanar waveguides, slot-lines, and modified transmission lines such as linked microstrip slot-lines, on the other hand, have lately been used in MICs. On both sides of the substrate, double-sided MICs successfully use a variety of transmission lines, including microstrip lines, slot lines, coplanar waveguides, and their modified transmission lines. Because of this, this form of MIC is known as a Both-Sided MIC [28].

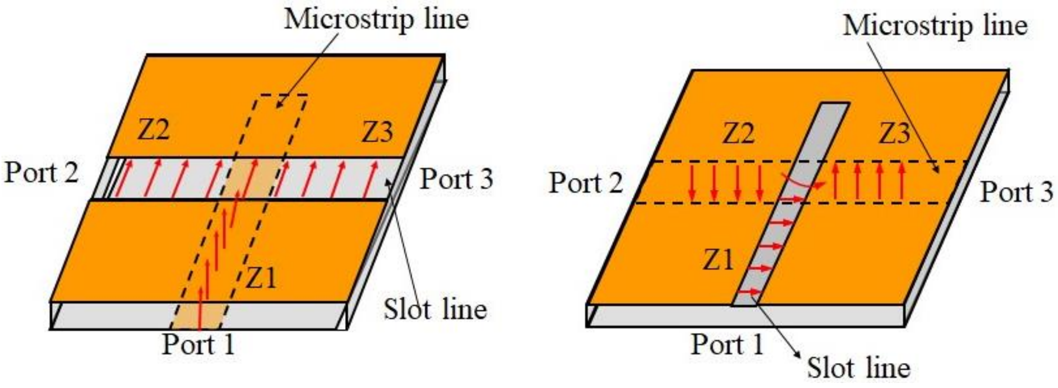
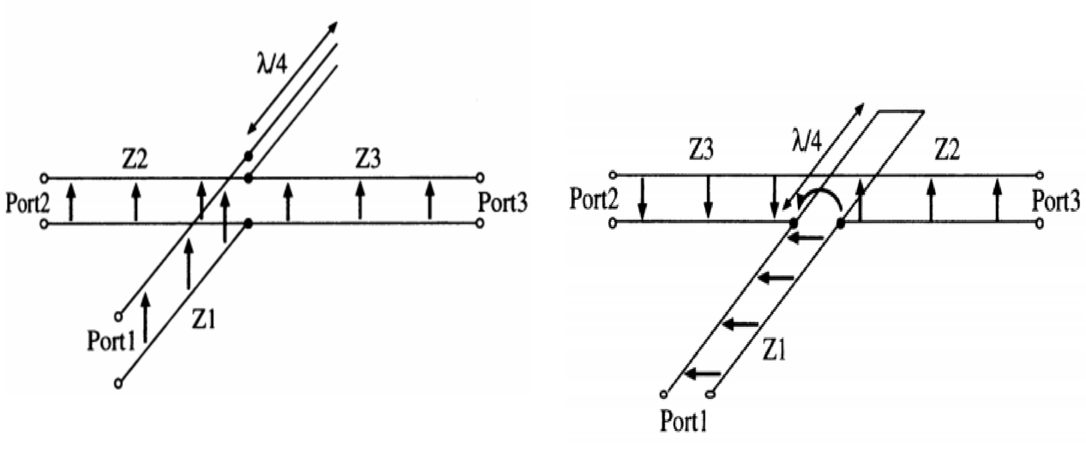


Figure 3.12: Line coupling and schematic electric field



(a) (b)

Figure 3.13: (a) Equivalent microstrip-slot branch circuit and (b) Equivalent slot-microstrip branch circuit

3.9.1 Branch Circuit Using Both-Sided MIC

There are two kinds of branch circuits using both-Sided MIC technology are explained in this section that is microstrip-slot branch circuit and the slot-microstrip branch circuit. Because of the using of the both-Sided MIC technology, the branch circuits have no bent lines and are composed of only straight and short lines, the feeding loss and the radiation loss can be expected to be small [29].

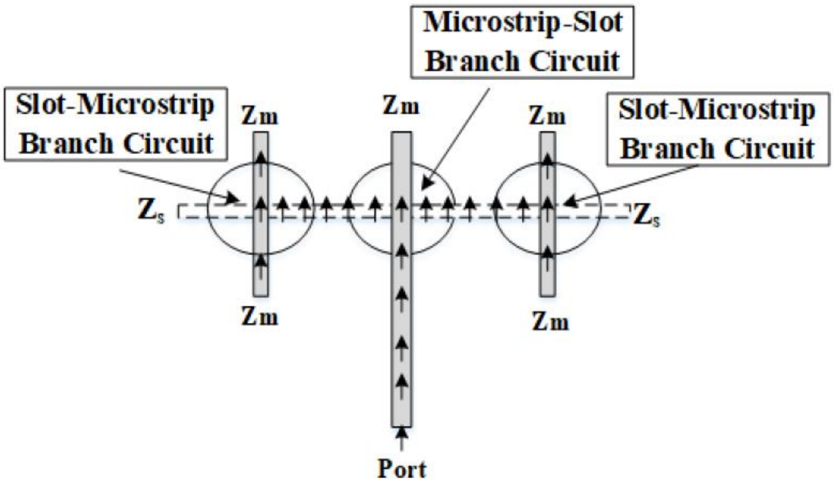


Figure 3.14: The equivalent circuit of microstrip-slot branch circuit and slot-microstrip branch circuit of the proposed feed network

3.9.2 Microstrip-Slot Branch Circuit

The microstrip-slot branch circuits are composed of microstrip line on a surface of a substrate and a slot line on the reverse side. The microstrip-slot branch circuit is a parallel power divider, so the condition for impedance matching is $Z_S = 2Z_m$. At the equal distance points from the branch point on the slot line, two divided signals have the same amplitude and are in phase in a very wide band [29-30].

3.9.3 Slot-Microstrip Branch Circuit

Figure 3.13 shows the configuration and equivalent circuit for a slot-microstrip branch circuit. The slot-microstrip branch circuit is a series power divider, so the condition for impedance matching is $Z_S/2 = Z_m$. At the equal distance points from the branch point on the microstrip line, two divided signals have the same amplitude and are out of phase in a very wide band [26-27].

3.9.4 Advantages of using Both-Sided MIC

The both-sided MIC’s technology has many practical advantages due to the effects of combining several kinds of transmission lines, and the effective use of both sides of the substrate. The advantages are as follows:

(i) Excellent Circuit Functions and great design Flexibility.

(ii) A very wide range of transmission line impedance is available.

(iii) According to integrate a number of transmission line transitions such as microstrip line and the slot line, series branch circuit and parallel branch circuit are easily realized. Two branch circuits are very useful for Both-sided MIC circuits.

(iv) The orthogonal transmission lines are easily constructed using the “even/odd transition modes”. In addition, a very tight line coupling is also achieved without any difficulty.

(v) Higher integration can be achieved by using both sides of the substrate effectively.

(vi) Active or passive devices are easily mounted in series with, or parallel to, transmission lines, because the Both-Sided MIC’s use coplanar type lines such as slot lines or coplanar waveguides.

3.10 Requirement of Gain Enhancement in Antenna Systems

In the ever-evolving landscape of wireless communication, the need for gain enhancement in antenna systems is more pronounced than ever. Antenna gain, a measure of an antenna's ability to focus transmitted or received signals in a specific direction, directly influences the efficiency and performance of communication links. In many scenarios, the demand for extended communication ranges, improved signal clarity, and enhanced data transfer rates necessitates antennas with higher gains. Gain enhancement becomes particularly crucial in applications such as long-range communications, satellite links, and wireless networks where the reliable and efficient exchange of information is paramount. Moreover, as communication systems continue to push the boundaries of what is achievable, the quest for innovative solutions to boost antenna gain becomes a driving force in advancing the capabilities of wireless technologies.

3.11 Applications of Microstrip Patch Array Antennas with Enhanced Gain

Microstrip patch array antennas with enhanced gain find applications in various fields due to their improved performance characteristics. Here are some potential applications:

(i) **Satellite Communication**

Microstrip patch array antennas with enhanced gain are crucial in satellite communication systems. The increased gain helps in achieving better link budgets, allowing for more reliable and efficient communication between ground stations and satellites.

(ii) **Radar Systems**

High-gain microstrip patch arrays are essential in radar systems for long-range detection and accurate tracking of targets. Enhanced gain improves the radar's sensitivity and extends its detection range, making it suitable for both military and civilian applications.

(iii) **Wireless Communication Networks**

In wireless communication systems, microstrip patch array antennas with enhanced gain are valuable for extending the coverage area and improving signal strength. This is particularly important in cellular networks, where the quality of communication depends on the antennas' ability to transmit and receive signals effectively.

(iv) **Aerospace and Aviation**

Microstrip patch array antennas play a crucial role in aerospace applications, including aircraft and Unmanned Aerial Vehicles (UAVs). Enhanced gain enables these antennas to maintain stable communication links over longer distances, contributing to reliable navigation and data transmission.

(v) **Remote Sensing**

Remote sensing applications, such as Earth observation satellites, benefit from microstrip patch array antennas with enhanced gain. These antennas facilitate the collection of high-resolution data over large areas, supporting environmental monitoring, disaster management, and agricultural applications.

(vi) **Point-to-Point Communication Links**

Microstrip patch array antennas are used in point-to-point communication links, such as microwave and millimeter-wave communication systems. Enhanced gain is crucial for achieving high data rates and reliable communication over long distances.

(vii) **Military and Defense Systems**

Military applications often require antennas with superior performance. Microstrip patch arrays with enhanced gain are employed in defense systems for communication, surveillance, and reconnaissance, providing a tactical advantage in the field.

(viii) **Internet of Things (IoT)**

In the context of IoT, microstrip patch array antennas with enhanced gain contribute to improved connectivity and data transfer rates. This is important for IoT devices in various sectors, including smart cities, healthcare, and industrial automation.

(ix) **5G Communication Systems**

As the deployment of 5G networks continues, antennas with enhanced gain become essential for delivering the high data rates and low latency promised by 5G technology. Microstrip patch arrays play a role in both base station and user equipment antennas in 5G networks.

(x) **Radio Astronomy**

In radio astronomy, where sensitivity and precision are paramount, microstrip patch arrays with enhanced gain can be employed for radio telescopes. These antennas help capture faint signals from celestial objects, contributing to advancements in astronomy.

In summary, the applications of microstrip patch array antennas with enhanced gain are diverse and span across communication, aerospace, defense, remote sensing, and emerging technologies like 5G and IoT. Their ability to provide reliable and high-performance communication makes them essential components in various advanced systems.

3.12 Summary

In this chapter firstly Microstrip Antenna and overview, its geometry, Basics characteristics and its advantages with limitations has been discussed. Thereafter for facilitating antenna design the mathematical analysis with all related equations have elaborately been mentioned. Different feeding methods with their limitations have also brought in picture. A Novel technique both-sided MIC has been introduced for gain enhancement by array with simpler feeding network. Both-sided MIC technique has many practical advantages due to the effect of combining several kind of transmission lines and the effective use of both-sides of the substrate. Finally the requirement of gain enhancement in antenna system has been discussed. Microstrip array antennas with enhanced gain find applications in various fields due to their improved performance characteristics.

CHAPTER 4

DESIGN OF A 2X2 MICROSTRIP ARRAY USING BOTH-SIDED MIC

4.1 Introduction

As a radiating component in communication systems with several applications, including wireless, radar, and satellite communication, microstrip patch antennas are becoming more and more popular as they provide such advantages in terms of profile, cost, and fabrication [35-36]. They also offer feeding systems that are simple to construct and integrate with active components, which make them more appealing [37]. Among the various antenna parameters, antenna gain is a critical aspect of any communication since many applications require long-distance coverage. With microstrip patches in communication, a single patch may have difficulty in meeting the criteria. Making an array to improve antenna gain is an immediate option. In recent years, many studies on microstrip array antennas have been conducted [38-42]. A matching network is required for a microstrip array antenna to transfer maximum power or signal to each individual element so that the signals can total up and propagate together, resulting in an increase in antenna size. Although multilayer stacked patch antennas provide a solution to this problem, they increase feeding complexity because individual feeding to each patch may be required [43]. To feed each patch layered in a multilayer, numerous ports are required, which demands several impedance-matched positions of the patch, which is difficult to locate. Other techniques for acquiring gain by microstrip array exist, but each has drawbacks [44-45]. The both-sided MIC technology uses both sides of the substrate for a microstrip antenna is an improvement in circuitry that allows for greater compactness and simplicity of integration with antenna components and allows antenna elements to avoid matching circuits as well as provides a solution to feed network complexity [46]. In [47], it has been demonstrated how employing both-sided MIC technology may boost antenna gain and simplify the design. The X-band frequency range remains an interesting requirement for communication engineers since it is used in radar and satellite communication to identify many human and natural beneficial causes. Many studies have been conducted on this frequency range for microstrip patch array antennas [48-49].

In this chapter, a microstrip antenna is constructed initially, followed by a feeding network employing a both-sided MIC technique, and finally, a 2x2 array is designed and simulated for gain enhancement at the X-band frequency.

4.2 Design Procedure

In design procedure at first the single element design has been carried out. Subsequently has been developed aiming to feed the proposed array. Finally a 2x2 array is designed by placing the single element in four ports of the feeding structure.

4.2.1 Single Element Design

First, a single patch antenna is designed for the X-band frequency range. A copper square patch with a thickness of 0.018 mm is placed on top of a Teflon substrate with a relative dielectric constant of 2.15 and a height of 0.8 mm. A microstrip line of 50Ω has been placed on top of the substrate from the edge of the antenna to the patch edge to feed the patch. At the edge of the patch the antenna input impedance is 220Ω. A quarter wavelength transformers are used for impedance matching. The impedance of the quarter wavelength transformer is 104.88Ω. The width of the microstrip and quarter wave transformer is designed in such way so that they maintain the required impedance for better matching without doing any notching in the radiating patch. The ground plane of the antenna is constructed from the same material as the patch. As shown in Figure 4.1, the input signal is inserted into the port, and the simulation is done using an Advanced Design System (ADS) version 2021.

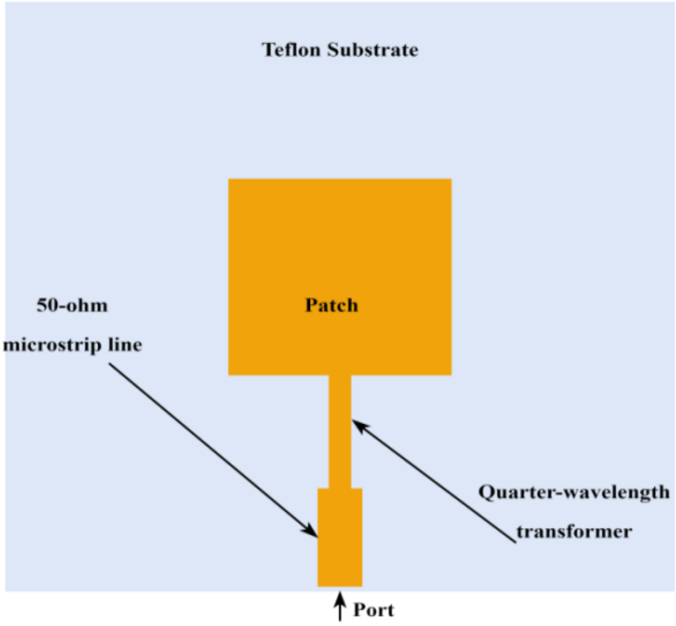


Figure 4.1: Structure of a single square microstrip patch with a microstrip line feed

4.2.2 Feeding Structure Design Using Both-Sided MIC

A feeding structure has been designed for 2x2 arrays using both-sided MIC technique. Both sides of the substrate are employed by transmission line. On the top of the substrate microstrip lines and another sides slots lines are employed. There not electrically connected but electromagnetically coupled. The slot lines are cut in to the ground plane in such way so that the impedance of the slot line is twice than that of microstrip line. In this case impedance of microstrip line is 50Ω and slot line is 100Ω. The required impedance in all sections is maintained by designing the appropriate width of all sections.

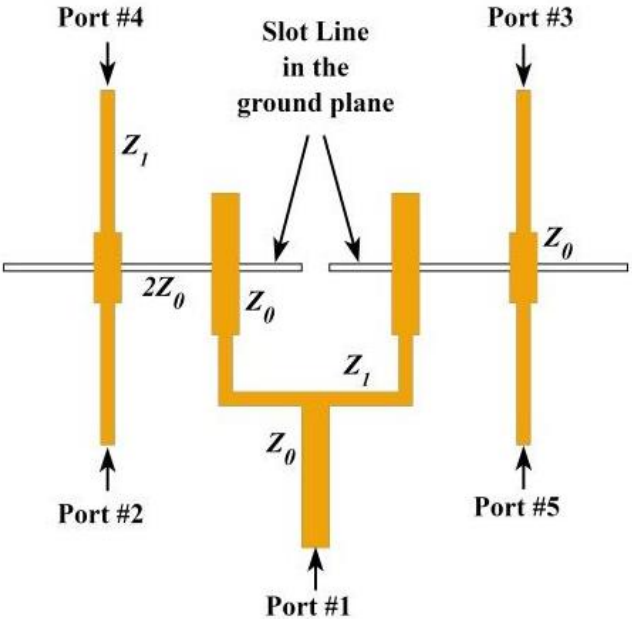


Figure 4.2: Feed network for the proposed array using both-sided MIC

Feed network for the proposed microstrip array antenna is depicted in Figure 4.2. The signal is routed into input port #1 before being separated into two microstrip lines, which are then coupled with the slot lines to produce the microstrip-slot branch. The network is completed by two more microstrip lines formed by slot-to-microstrip line branches and makes room for four patches. The feed network is developed and simulated numerous times for optimal results after inserting four pins in place of four patches. Since ports #2, #4, and port #3, #5 is symmetrical, only ports #2 and #3 with respect to port #1 are being evaluated here. The isolation between ports has been inspected, and it is obvious from Figure 4.3 that the feed structure has excellent isolation between ports.

In figure 4.3, S_{23} curve indicates that no signal is transmitted back from port #2 to port #3 as it exhibits less than -10 dB return loss for the entire 8~12 GHz frequency range. The same way port #4 is completely isolated from port #5.

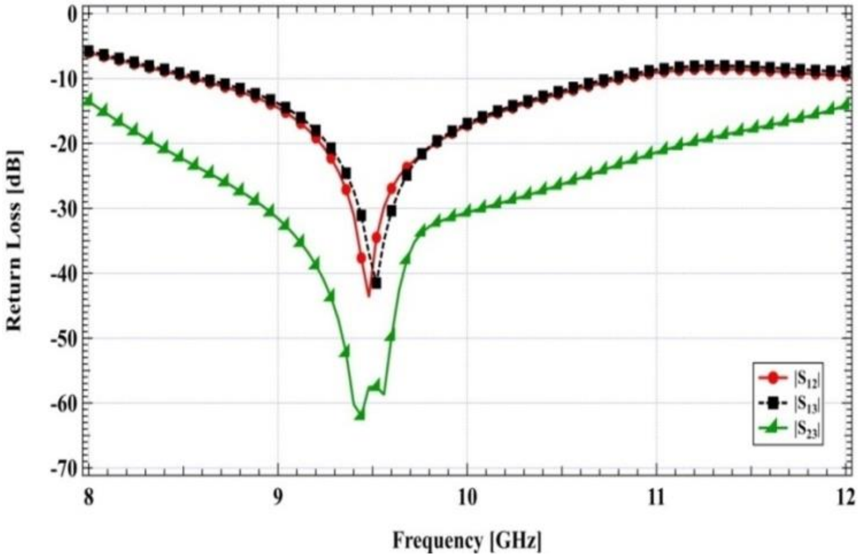
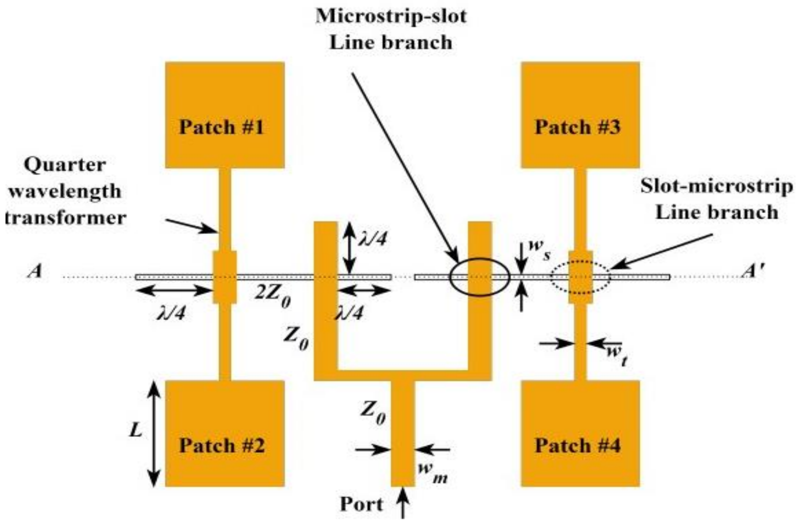


Figure 4.3: Impedance matching of the feed network

4.2.3 Array Design and Working Principle

Four patches are put in place of the four pins in the feed network. Figure 4.4 depicts the array’s structure. Figure 4.4(a) shows the top view of the proposed array antenna and Figure 4.4(b) shows the cross-section view along AA’ of the array.



(a) Top view

(b) Cross-sectional view along AA’

Figure 4.4: Design structure of the proposed micro strip array antenna

The slot is cut in the ground layer and patch and the microstrip lines are on the top of the Teflon substrate. As the signal travels across the microstrip line from port to port, it is divided into two equal amplitude and equal phase signals. The signal is connected to two slot lines while propagating along two microstrip lines in the ground plane of the antenna, forming a microstrip-slot junction. To improve signal isolation, both the slot line and the microstrip line are extended by a quarter wavelengths from the microstrip-slot line junction. The phase of the signals remains unchanged as they travel across slot lines. At the slot-microstrip line intersection, the phase is inverted and fed evenly to four patches. The current distribution in each patch is depicted in figure 4.5.

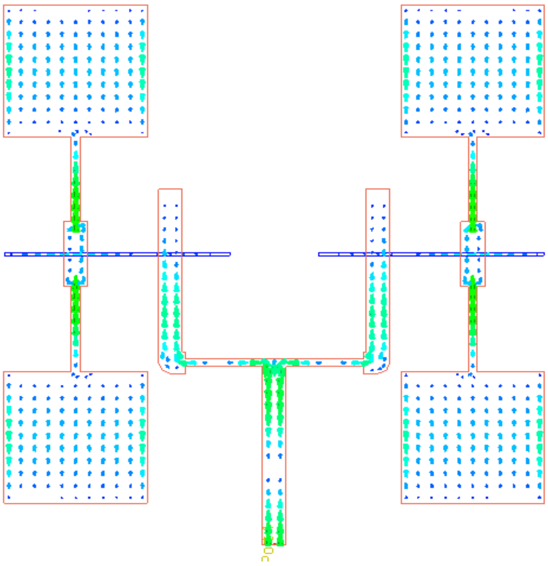


Figure 4.5: Simulated Current Distribution

4.2.4 Design Parameters

A 2x2 Array is designed and optimized by simulation to achieve the desired result. All the values and dimensions of the array are presented in Table 4.1.

Table 4.1: Design parameters of the proposed microstrip array antenna.

Parameter	Value
Substrate	Teflon Glass Fiber
Relative dielectric constant, ε_r	2.15
Height of substrate, h_s	0.8 mm
Patch dimension , L x W x t	9.7 mm x 9.7 mm x 0.018 mm
Micro strip line impedance, Z_0	50 Ω
Qtr wavelength transformer impedance, Z_1	104.88 Ω
Qtr wavelength transformer width, w_t	0.8 mm
Micro strip line width, w_m	2.2 mm
Slot line width, w_s	0.2 mm
Overall size of antenna	40 mm x 40 mm

4.3 Result Analysis

For result analysis the return loss for both single element and array are observed. The radiation pattern and broadside gain also observed. Arrays radiation efficiency and current distribution in all the patches also analyzed. However, the obtained all results from the simulated proposed array are illustrated below.

4.3.1 Return Loss

Figure 4.6 displays the return loss for both the single patch and array antennas. The graph clearly shows that the single patch and suggested array are properly matched in resonance frequency of 10 GHz. Both antennas have a return loss of less than -20 dB at the resonant frequency. The designed array perfectly matched at its resonant frequency as it exhibit the return loss of -45dB.

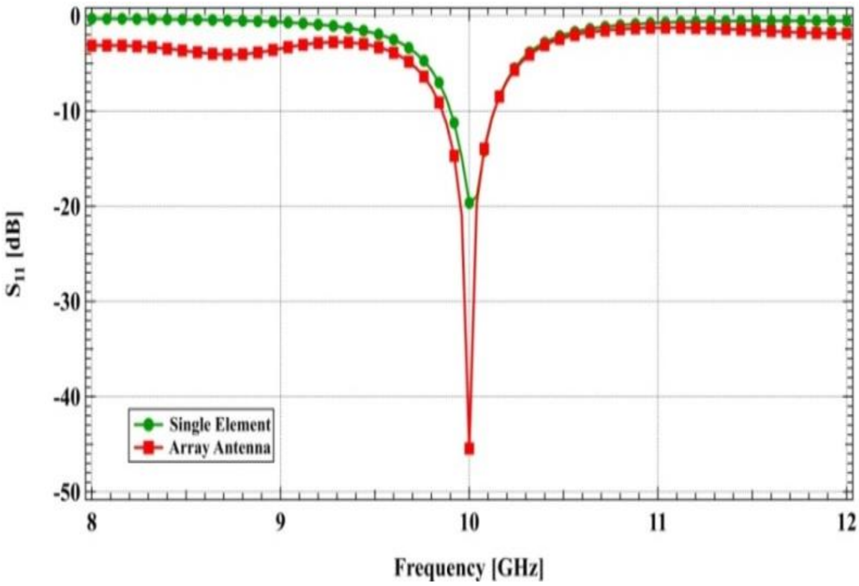


Figure 4.6: Simulated return loss of the proposed antenna

4.3.2 Radiation Pattern

The proposed microstrip antenna’s 3D radiation pattern is shown in Figure 4.7. The antenna exhibits a very well-shaped beam in the broadside direction, as seen in the picture. It is also evident that the side lobe and back lobes are almost negligible with respect to the main lobe.

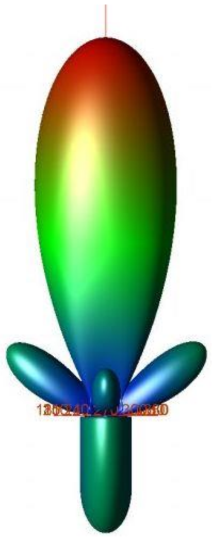


Figure 4.7: Simulated 3D radiation pattern of the proposed microstrip array antenna

The two-dimensional radiation beam obtained by cutting along phi = 0^0 is illustrated in Figure 4.8 and clearly shows that the designed array antenna is very much directed.

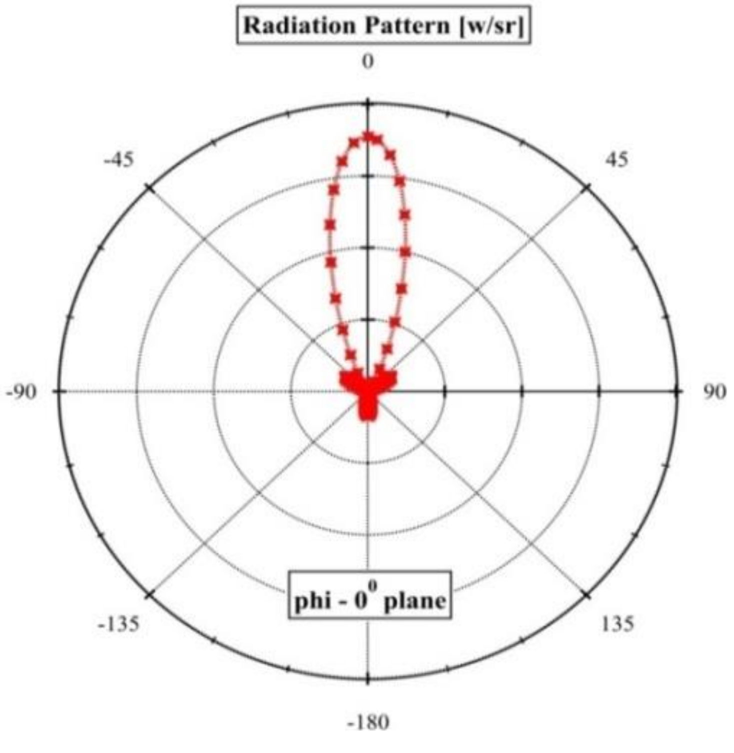


Figure 4.8: 2D radiation pattern of the proposed array antenna versus theta

4.3.3 Broadside Gain

Figure 4.9 depicts the proposed array antenna's simulated broadside gain. The graph clearly reveals that the antenna has a gain of roughly 25.02 dB in the broadside direction. The graph also indicates that the side lobe gain of the array antenna is about only 5 dB which indicates that the antenna shows high gain and high directivity in the direction of main lobe.

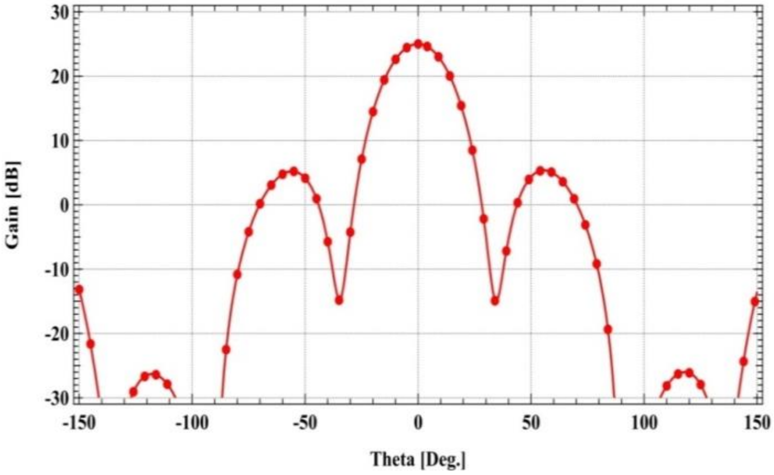


Figure 4.9: Simulated broadside gain of the proposed array antenna

4.3.4 Frequency vs Isotopic Gain and Directivity

Figure 4.10 illustrate the gain vs frequency of the proposed array and the single patch antenna. The graph clearly illustrates that the proposed array antenna has a large gain in the resonance frequency, which is significantly more than the gain of a single-element antenna. The single element exhibits around 7 dBi gains at the resonance frequency, but the array exhibits approximately 12.59 dBi gains at that frequency. It is also clear from the figure that the antenna has a maximum 13.42 dBi gain in the X-band frequency range.

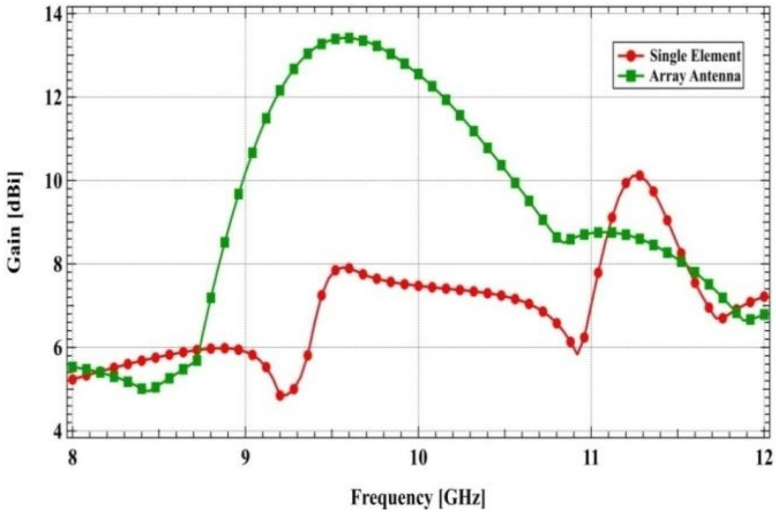


Figure 4.10: Simulated isotropic Gain with respect to frequency of the proposed antenna

Figure 4.11 shows the directivity vs frequency. The antenna is directive at its resonant frequency.

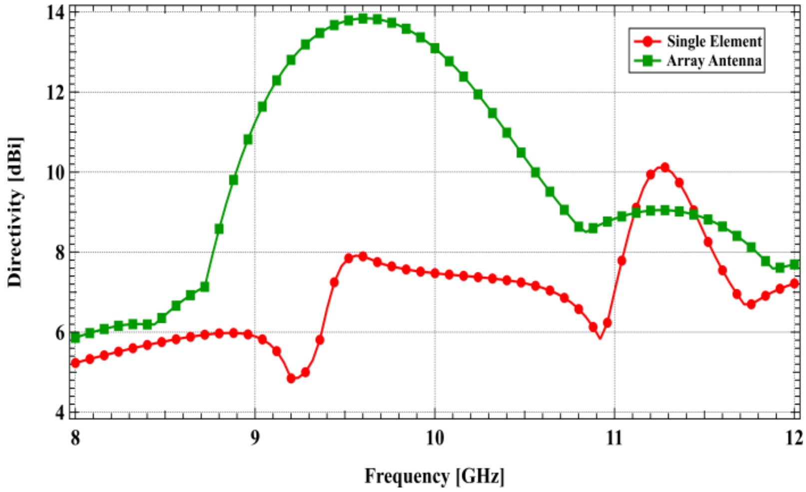


Figure 4.11: Directivity with respect to frequency of the proposed antenna

4.3.5 Antenna Efficiency

The radiation efficiency of a microstrip array antenna is a crucial performance metric that quantifies how effectively the antenna converts input power into radiated electromagnetic waves. The efficiency of the feeding network influences overall antenna efficiency. Feed lines used in microstrip patch antennas, exhibit some inherent resistance which contributes to ohmic losses in the form of heat and reduces the radiation efficiency. Using Both-sided MIC, minimizing the use of conductive material in feed line which results in the increase of over all radiation efficiency. Figure 4.12 displays the antenna efficiency, which demonstrates that the antenna is capable of radiating efficiently because it offers 86% radiation efficiency at its resonance frequency.

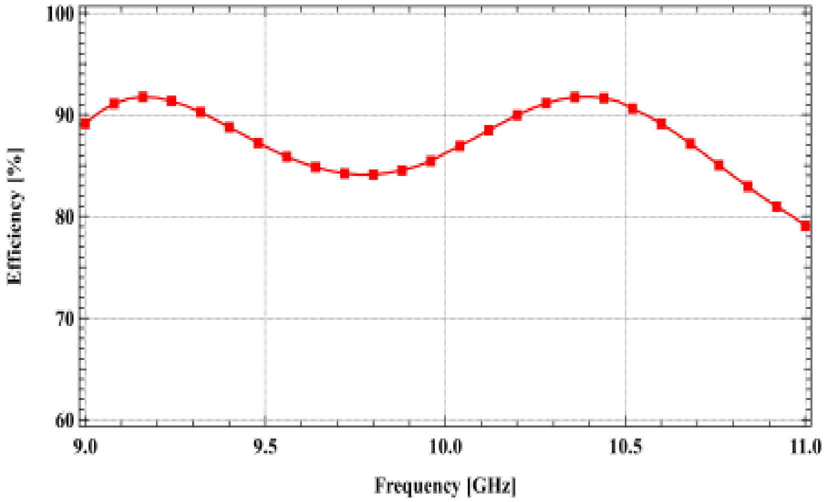


Figure 4.12: Antenna Efficiency with respect to frequency of the proposed array antenna

4.4 Summary

A four-element (2x2) array antenna for the purpose of high gain for use in the field of X-band frequency range is designed and simulated in this chapter. The simulated results have clear evidence that an array can increase the gain of an antenna. Using both-sided MIC can simplify the complexity of the feed network and make the array efficient for radiating high directive beams. The designed microstrip array antenna is properly matched at 10 GHz and has an isotopic gain of 12.59 dBi at resonance frequency. The antenna has a broad side gain of 25.02 dB, indicating its effectiveness in radiating electromagnetic waves in the desired direction. This high broadside gain is crucial for the applications where precise and focused signal transmission is essential for optimal performance. The efficiency of the designed antenna is measured at an impressive 86% at its resonance frequency as the conduction loss (i^2r loss) is reduced in feeding structure for using both-sided MIC. This metric reflects the antenna's ability to convert input power into radiated energy with high efficiency. High radiation efficiency is a critical factor in ensuring that the antenna maximizes its operational capabilities while minimizing power losses.

In summary, the designed four-element array antenna, enhanced by both-sided MIC technology, presents a compelling solution for achieving high gain in the X-band frequency range. With proper impedance matching, isotropic gain, maximum gain, broadside gain, and radiation efficiency, the antenna demonstrates its suitability for applications requiring precision, reliability, and efficiency in the transmission and reception of signals.

CHAPTER 5

A 4x2 MICROSTRIP ARRAY DESIGN FOR GAIN ENHANCEMENT

5.1 Introduction

In the realm of wireless communication, achieving high-gain antennas is paramount for enhancing signal strength, extending communication range, and improving overall system performance. Among the various antenna designs available, the microstrip patch antenna (MPA) has emerged as a popular choice due to its advantageous characteristics. MPAs are known for their compact size, lightweight construction, cost-effectiveness, ease of fabrication, and versatility in mounting options [1-2]. These qualities make them particularly well-suited for a wide range of applications, including satellite communication, radar systems, wireless networks, and mobile devices. However, despite their widespread adoption, MPAs are not free from limitations. One significant drawback is their inherent low gain response [1], which can restrict their effectiveness in long-range communication scenarios or environments with weak signal strength. Recognizing this challenge, researchers have dedicated efforts to develop techniques aimed at boosting the gain of microstrip patch antennas.

A notable approach to enhancing MPA gain involves the integration of open stubs into the antenna design, as demonstrated in [1]. By strategically incorporating these elements, researchers were able to achieve a notable gain of approximately 9 dBi, coupled with an impressive antenna efficiency of around 80%. Additionally, exploring alternative substrate materials, such as air gaps instead of traditional dielectric substrates, has shown promise in further enhancing gain and efficiency. However, this method requires meticulous optimization of parameters such as slot length and spacing, as well as careful consideration of potential integration challenges into circuitry. Another avenue for gain enhancement is the utilization of supplementary technologies, such as waveguides. In [51], researchers explored the coupling of waveguides with microstrip antennas, albeit achieving a slightly lower gain of 8.79 dB. However, when multiple microstrip patch antennas are combined into arrays, significant gains can be realized. For instance, the assembly of a 27x25 patch array discussed in [3] resulted in an impressive gain of 30 dBi, showcasing the potential of array configurations to substantially improve antenna performance. Nevertheless, not all array configurations yield equally significant gains. For instance, while a 5x5 array discussed in [53] employing a series-fed approach only provided a gain of 15 dBi at the resonance frequency, indicating the importance of careful array design and feeding techniques.

Feeding techniques play a crucial role in maximizing the performance of antenna arrays. Using dividers to feed each patch of an array through microstrip lines, as explored in [54] and [55], offers one such method. Despite promising gains achieved with arrays of 8 and 16 elements, impedance matching remains a challenge, particularly as the number of elements increases. To address impedance matching challenges, both-sided Microstrip Integrated Circuit (MIC) techniques have been investigated [57-58]. By utilizing both sides of the substrate, these techniques simplify the design process and reduce circuit complexity, offering a promising avenue for improving array performance.

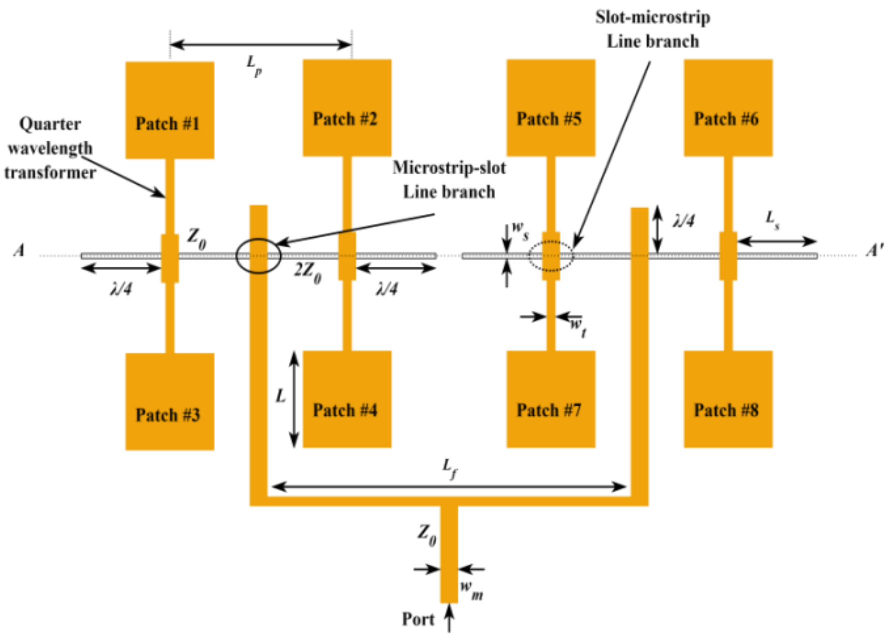
Continuing the pursuit of high-gain antenna solutions, the current study introduces a 4x2 microstrip patch array antenna design for further gain enhancement. Leveraging simulation tools such as Advanced Design System (ADS-2021), researchers aim to explore innovative design strategies and optimize antenna performance in pursuit of enhanced wireless communication capabilities. As a continuation of my previous work [1], a 4x2 microstrip patch array antenna has been designed for further gain enhancement.

5.2 Design Procedure

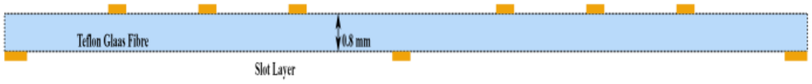
This section provides the antenna design with optimum design parameters as well as the array's working principle. The Advanced Design System (ADS-2021) is used for the design and simulation of the proposed array antenna.

5.2.1 Array Design

Figure 4.1 shows the suggested microstrip patch array antenna's design structure. The Teflon substrate supports the antenna, which has a relative dielectric constant of 2.15. On the ground plane, a 0.2mm wide slot line is carved in the ground plane to implement double-sided MIC technology. Above the substrate, eight patches are positioned in a 4x2 pattern.



(a) Top view



(b) Cross-sectional view along AA'

Figure 5.1: Complete structure of the proposed microstrip array antenna where double-sided MIC technology is used

The antenna's top view is depicted in Figure 5.1a and its cross-sectional view along AA' is shown in Figure 5.1b. Table 5.1 lists the optimized design parameters along with their respective values.

5.2.2 Array Working Principle

At the microstrip-slot junction shown by the circle in Figure 5.1, a 50Ω microstrip transmission line that feeds the antenna splits into two equal lines, each of which terminates as an open stub. The signal traveling along the microstrip line then traveled via the slot line up to the junction (slot-microstrip junction) of the two lines before splitting into two equal, out of-phase signals and reaching the patches. At the microstrip slot junction, it divides into two equal, in-phase signals, which is what happens next. The patches from #1 through #4 and #5 through #8 combine to form a 2x2 array. Ultimately, patches are used to create a 4x2 array. The signal travels through the microstrip and slot lines in a manner that is consistent throughout all patches. Right and left 2x2 arrays ignite at the same phase and function as two coherent patch elements. As a result, the entire array of 4x2 functions as one antenna and radiates a narrow beam in the broadside direction.

5.2.3 Power Divider in Junctions

A microstrip-slot power divider is depicted by the circle in Figure 5.1, while a slot-microstrip power divider is indicated by the dotted circle.

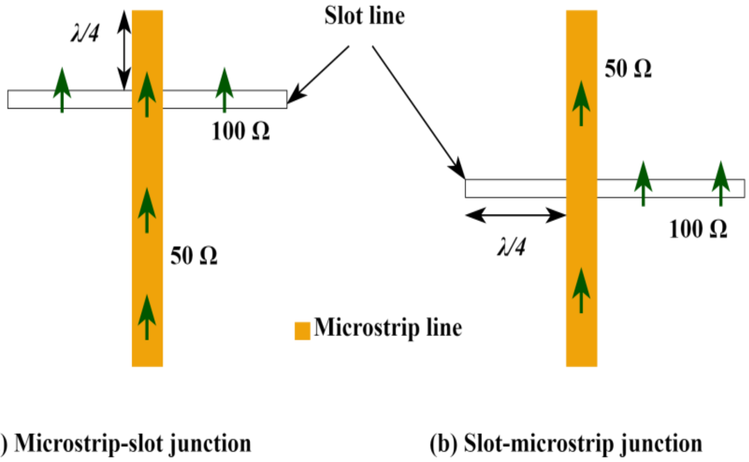


Figure 5.2: Power divider, (a) micro strip-to-slot junction power divider (b) slot-micro strip junction power divider

Figure 5.2 displays the details of the two power dividers with electric field design. The slot line impedance should be twice as large as the microstrip line impedance because the microstrip-slot power divider is a parallel divider. A phase signal is divided into two equal amplitude signals by this divider. The impedance of the microstrip line should be half that of the slot line, which is 50Ω, since the slot-microstrip power is a series power divider, as shown in Figure 5.2(b) [57]. Signals are split into two equal-amplitude out of-phase signals by the series divider. This setup employs both sides MIC technology, resulting in each patch having an identical electric field arrangement and radiating a beam pointed to the broadside direction.

5.2.4 Current Distributions in the Array Elements

Because of the use of the both-sided MIC in the feeding structure, each patch of the array experienced identical electric field as fed.

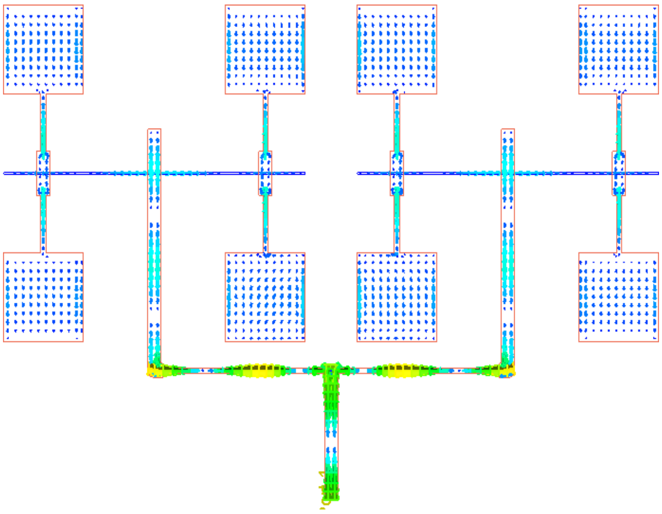


Figure 5.3: Simulated current distribution of the proposed array antenna

Figure 5.3 depicts the proposed array antenna’s current distribution. Because the antenna’s two row elements, each of which contains four elements, receive the split signal from slot micro strip junctions, the elements’ electric fields should be in the same direction, as shown in the figure.

5.2.5 Design Parameter

The simulated optimized design parameters of the proposed antenna is displayed in table 5.1.

Table 5.1: Design parameters of the 4x2 microstrip patch array antenna

Parameter	Value
Patch dimension, L x W x t	9.7 mm x 9.7mm x 0.018mm
Microstrip line impedance, Z_0	50Ω
Microstrip line impedance, Z_1	104.88Ω
Microstrip line width, w_m	2.2 mm
Quarter wavelength transformer width, w_t	0.8 mm
Slot line width, w_s	0.2 mm
Patch to patch length, L_p	27 mm
Feed to feed length, L_f	47 mm
Overall dimension of Antenna	80 mm x 60 mm

5.3 Result Analysis

In this section to achieve the optimized result a parametric analysis had been carried out. The radiation pattern, broadside gain and radiation efficiency has also been observed by optimization.

5.3.1 Parametric Analysis

A parametric analysis had been carried out by changing patch to patch and feed to feed distance and observe the return loss and gain.

5.3.1.1 Variation in Patch to Patch Distance

The outcome of the simulated return loss for various patch to patch lengths is shown in Figure 5.4. The figure makes it obvious that as the distance between patches is changed, the antenna's resonant frequency changes as well as the impedance.

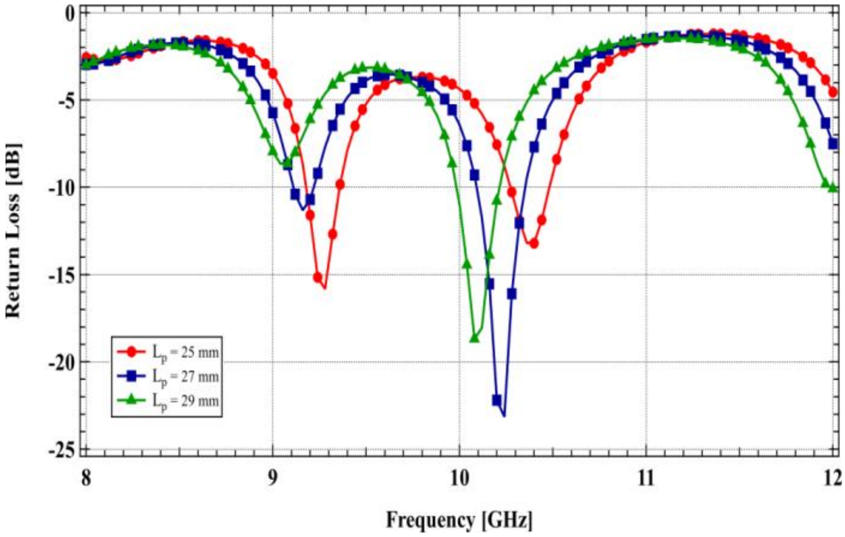


Figure 5.4 Reflection coefficients for various patch-to-patch lengths of the proposed antenna

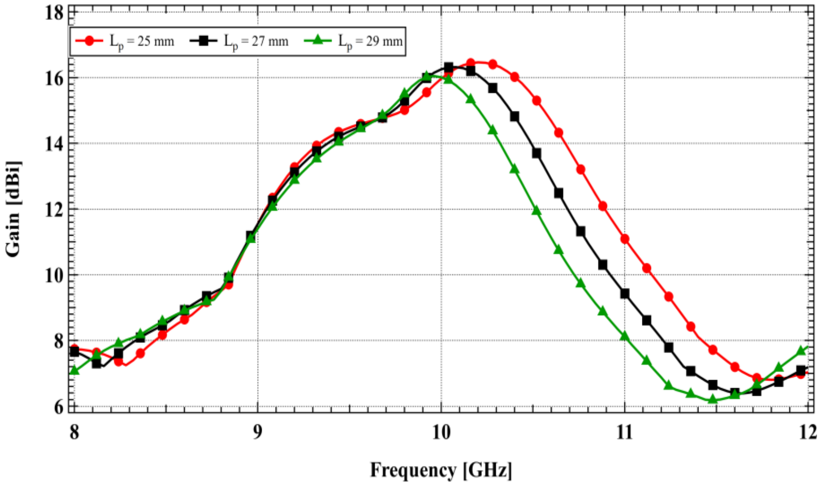


Figure 5.5: Simulated Gain versus frequency for for various patch-to-patch lengths

The resonance moves to the left in the frequency axis as the distance grows. The antenna exhibits its optimum impedance matching at L_P = 27 mm. The resonance, as is evident from Figure 5.5, moves along with the variation in distance, affecting the maximum antenna gain.

5.3.1.2 Variation in Feed to Feed Distance

The simulation's output for various feed-to-feed lengths is shown in Figure 5.6. The figure makes it obvious that, no matter how close or far apart the feeds are the antenna's resonance frequency remains constant.

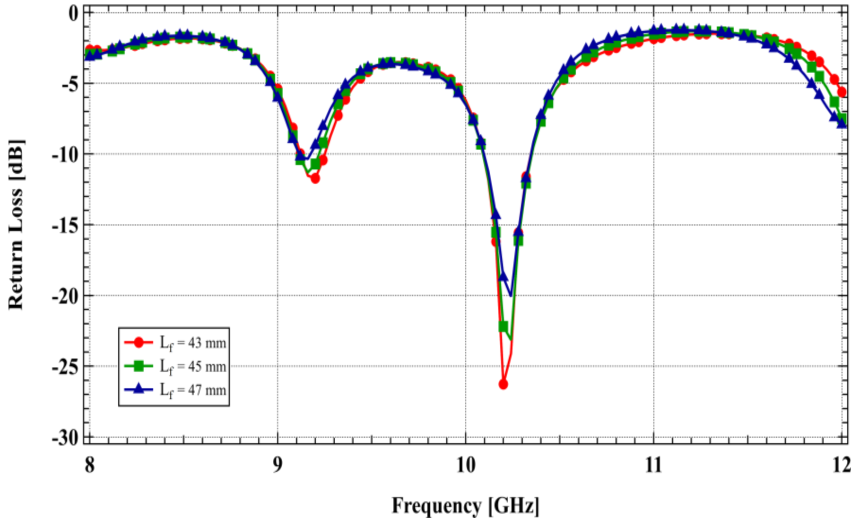


Figure 5.6: Simulated return loss for various feed-to-feed length of the proposed antenna

The antenna's impedance is the only thing that changes when the distance increases or decreases. The antenna's impedance matching is optimum at L_f = 47 mm. As the distance changes, the maximum antenna gain likewise changes in amplitude, as seen in Figure 5.7.

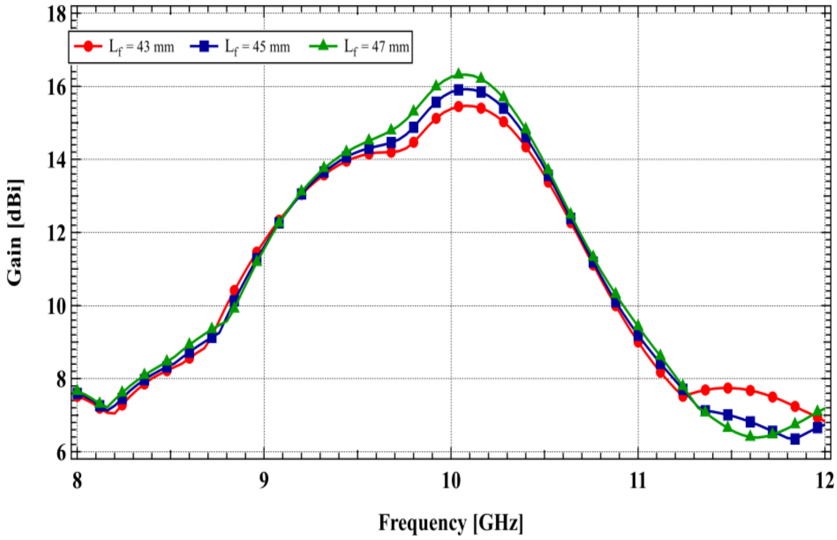


Figure 5.7: Simulated isotropic Gain versus frequency for different L_f

5.3.1.3 Variation of Slot Length Extension

The performance of the antenna impedance is also affected by the slot extension denoted by L_S. When the slot extension is the same length as a quarter wavelengths, the antenna exhibits optimal impedance matching. It is evident from Figure 5.8 that the optimum impedance performance occurs for length L_S = 5.0 mm, which is equal to a quarter wavelength.

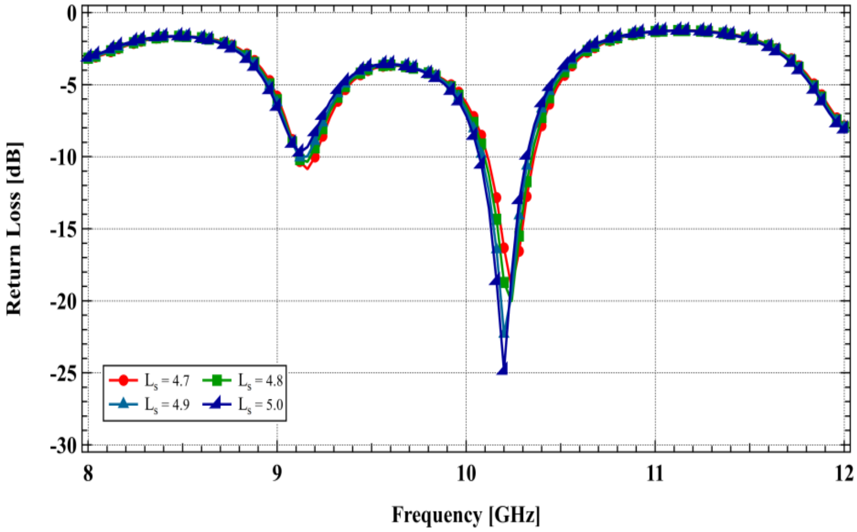


Figure 5.8: Simulated return loss for various L_S of the proposed antenna

5.3.2 Optimization of Results

Through the parametric analysis i.e. by the variation of patch to patch distance and feed to feed distance optimized value of return loss and isotopic gain is obtained at L_p = 27mm, L_f = 47mm and L_S = 5.0 mm .

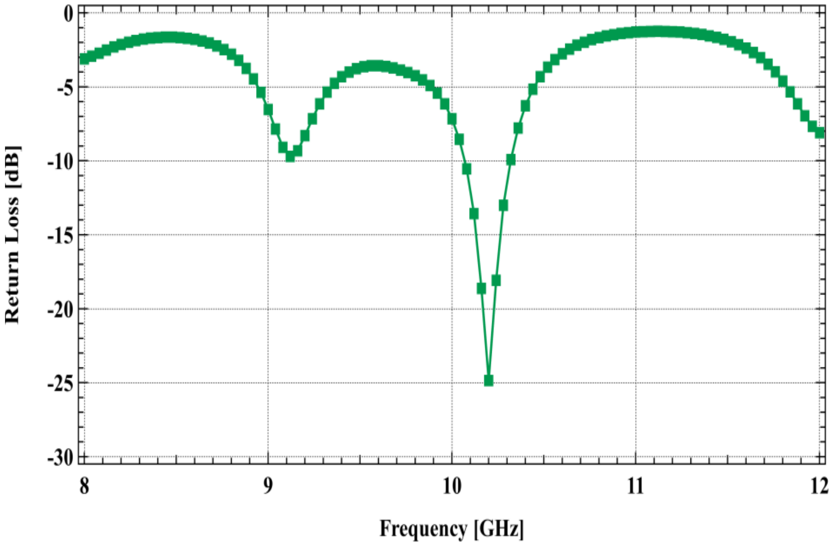


Figure 5.9: Return loss of the proposed 4x2 micro strip patch array antenna

The figures in Figure 5.9 and Figure 5.10 show the optimal return loss and gain of the suggested antenna. From figures, it is observed that the proposed 4x2 microstrip patch array antenna has a return loss of approximately -25 dB at the resonance frequency of 10.24 GHz, which indicates that the antenna is well matched at the resonance frequency. Furthermore, the antenna has an isotopic gain of 16.12 dBi at the resonance frequency.

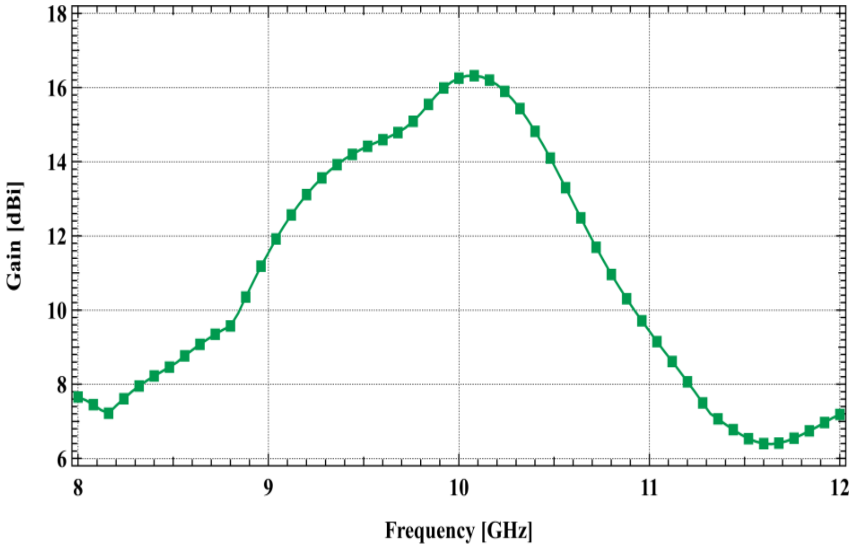


Figure 5.10: Optimized isotropic gain with respect to frequency of the proposed antenna

5.4 Radiation Pattern

The proposed 4x2 microstrip antenna's 3D radiation pattern is shown in Figure 5.11. The antenna exhibits a very well-shaped beam in the broadside direction, as indicating in the picture. In this case the beam has become more directed and narrower. It is also evident that the side lobe and back lobes are almost negligible with respect to the main lobe.

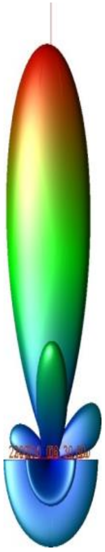


Figure 5.11: Simulated 3D radiation pattern of the proposed antenna

5.5 Broadside Gain

In Figure 5.12, the simulated broadside gain in dB for both plane cuts is displayed. The diagram displays the antenna’s 3 dB half-power beam width (HPBW) in the phi = 90^0 plane and 30^0 in the phi = 0^0 plane. Because the array extended only horizontally, resulting in four elements in the horizontal direction and two elements vertically aligned, the radiation pattern had two different beam widths for two separate planes. And it has a broad side gain of 32dB.

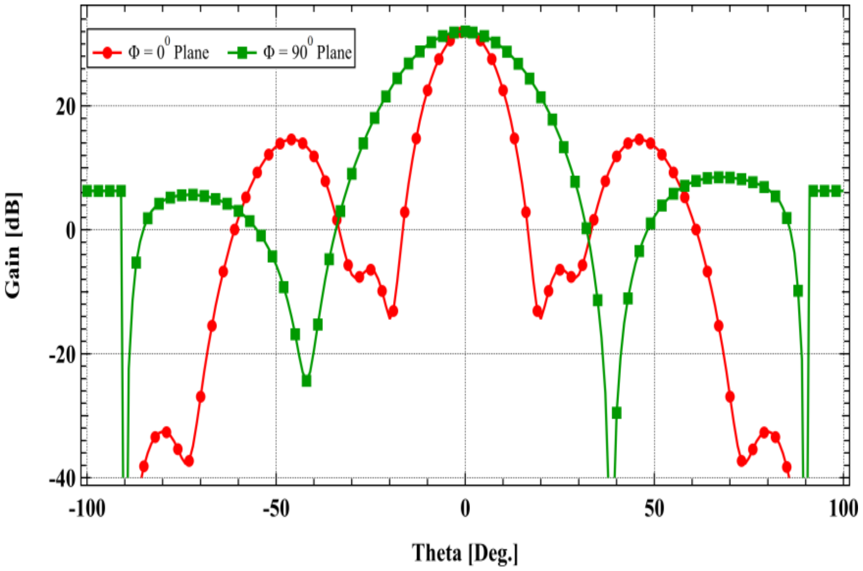


Figure 5.12: Simulated 2D radiation pattern of the proposed array antenna versus theta

5.6 Antenna Efficiency

The radiation efficiency of a microstrip array antenna refers to the portion of input power that is effectively radiated into space as electromagnetic waves. It is a measure of how well the antenna converts electrical power into radiated power. The radiation efficiency (η) is typically expressed as a percentage. A perfect antenna would have 100% radiation efficiency, meaning all the input power is radiated, but in practical antennas, losses occur in various components such as feed network, dielectric substrate, and radiation resistance.

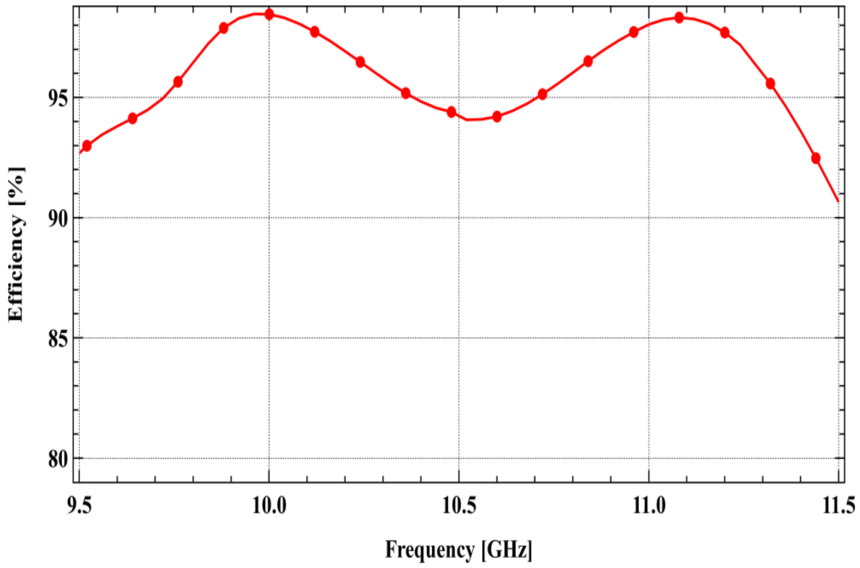


Figure 5.13: Efficiency of the proposed array antenna

Figure 5.13 displays the antenna efficiency, which demonstrates that the antenna is capable of radiating efficiently because it offers 97% radiation efficiency at the resonance frequency.

5.7 Comparison with Relevant Works

A Comparison with some previous work has been given in Table 5.2. The proposed 2x2 and 4x2 array exhibit maximum broadside gain of 25.02dB and 32dB respectively where as other arrays of same number of elements have very lesser gain. Furthermore, the proposed arrays exhibit notably lower return loss, indicating enhanced impedance matching compared to their counterparts. This improved matching is a significant advantage. Additionally, the antenna efficiency of the proposed arrays is remarkable, reaching 86% for the 2x2 array and 97% for the 4x2 array. These efficiencies surpass those of the compared designs by a significant margin. It's worth noting that none of the referenced papers utilize the both-sided MIC technique in their antenna designs. This underscores the innovative approach taken in the proposed designs. The integration of the both-sided MIC technique not only simplifies the design process but also contributes to the observed improvements in gain and efficiency. Overall, these findings highlight the efficacy of incorporating both-sided MIC in antenna design, resulting in superior performance metrics compared to conventional approaches.

Table 5.2: Comparison with Relevant Works

Ref.	Array Element	Return Loss	Broadside Gain	Efficiency	Remarks
[12]	2 x 2	-16dB	7.713dB	-	Intl Conference, India, 26-28 May 2023
[10]	2 x 2	-30dB	12.5dB	-	GS journal, Apr 2022
[11]	2 x 2 4 x 2	-14.5dB -13dB	7.2dB 10.1dB	49% 45%	BJET, AUG 2017
[1] This work	2 x 2	-45dB	25.02dB	86%	ICICT4SD, 2023
[2]	4 x 2	-25dB	32dB	97%	ICCIT, 2023

5.8 Summary

This chapter introduces a 4X2 microstrip array antenna design for further gain enhancement using both-sided MIC technology. The proposed antenna has a very high gain of 16.12 dBi at the resonance frequency of 10.24 GHz, and the return loss value of -25 dB. The antenna has a 3 dB Half Power Beam Width (HPBW) of 60^0 in the $\varphi = 90^0$ plane and 30^0 in the $\varphi = 0^0$ plane, and it is appropriately oriented broadside. The antenna exhibits a very well-shaped beam in the broadside direction and the beam has become more directed and narrower than that of the previous one. It exhibits maximum broadside gain of 32dB, indicating its effectiveness in radiating electromagnetic waves in the desired direction. This high broadside gain is crucial for the applications where precise and focused signal transmission is essential for optimal performance. The antenna attains 97% of efficiency at the resonance frequency as the conduction loss (i^2r loss) is reduced in feeding structure for using both-sided MIC.

CHAPTER 6

CONCLUSION

6.1 Summary of Findings

In conclusion, the research presented in this thesis focused on the design and optimization of a microstrip array antenna for gain enhancement using both-sided MIC technique for simplifying the feeding structure. The initial design of a single microstrip patch antenna demonstrated proper resonance at 10 GHz, establishing the foundation for subsequent array configurations. The designed 2x2 array antenna is properly matched at 10 GHz with an impressive return loss of -45 dB and has a maximum isotropic gain of 13.42 dBi in the specified X-band frequency range. By increasing the number of patches to a 4x2 array, the maximum isotropic gain of 16.12 dBi is observed at its resonance frequency. The implementation of both-sided MIC technique proved effective in achieving equitable signal distribution, reduction of conduction loss (i^2r loss), leading to high gain and directed beam patterns with a simplified feeding network. By using quarter wavelength impedance transformer for matching, the all elements are fed at their edge and hence unnecessary alteration of patches' geometry has been avoided in the design. The 2x2 microstrip patch array demonstrated impressive results, including a well-shaped 3D radiation pattern, minimized side lobes and back lobes, and the antenna exhibit the maximum broad side gain of 25.02 dB with an efficiency of 86%. Again by increasing the number of elements the designed 4x2 array has the radiation pattern with more focused and narrower beam. In this case the maximum broad side gain is 32dB and antenna efficiency attains 97% at the resonance frequency. The proposed array outperformed larger array configurations in terms of gain, highlighting the advantages of both-sided MIC technology in achieving significant gains while simplifying the design. A Comparison with some previous work has been given in Table 5.2. In conventional array cases it was observed that the antenna efficiency reduced with the increase of array elements because of losses in transmission line [11]. It is to be mentioned that none of the compared papers uses the both-sided MIC.

In essence, the utilization of the both-sided MIC technique in antenna design not only streamlined feeding structures but also propelled gains and efficiencies to unprecedented levels, solidifying its position as a transformative innovation in the field.

6.2 Contributions

This research makes several notable contributions to the field of microstrip patch antennas and array designs. The incorporation of both-sided MIC technique proved instrumental in achieving compactness, simplicity in feeding network integration, and substantial gain enhancements in the proposed microstrip patch array. The array (2x2 and 2x4) demonstrated superior gain characteristics, validating the effectiveness of the designed feeding network and array structure in achieving high gain. The utilization of both-sided MIC technology not only enhanced gain but also simplified the overall design by addressing feed network complexities, providing a promising avenue for future antenna designs. As the internal losses in feeding line decreases, the antenna efficiency also increased significantly. It also solves the heating problem.

6.3 Future Scope of Work

While this research has achieved significant milestones, several avenues for future work can be explored. By the simulated results fabrication can be done for real-world testing and analyze performance of the proposed microstrip array antenna. Investigate the integration of active components to enhance the functionality of the microstrip array for specific applications such as phased array systems. Explore advancements in MIC technologies and materials to further enhance compactness, integration, and overall performance in microstrip array designs.

In conclusion, this research contributes valuable insights into the design and optimization of microstrip array antennas, particularly in the context of both-sided MIC technology. The findings open up opportunities for continued advancements in antenna technology, paving the way for enhanced communication systems.

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