DESIGN AND ANALYSIS OF A MICROSTRIP PATCH ANTENNA ARRAY FOR 5G APPLICATIONS

MSC THESIS

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As thesis research advisors, we certify that we have read and evaluated this thesis prepared, under our guidance, by Atomsa Megersa Mamo. "Design and Analysis of a Microstrip Patch Antenna Array for 5G Applications". We recommended the submission of the thesis for the partial fulfillment of the requirements for the degree of Master of Science in Communications System Engineering.

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As members of the Board of Examiners of the MSc thesis open defense examination, we certify that we have read, and evaluated the thesis prepared by Atomsa Megersa, and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in **Communication System Engineering (Electrical and Computer Engineering).**

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STATEMENT OF THE AUTHOR

By signing below, I affirm that this thesis is my original work. I have adhered to all ethical and technical standards of scholarship in its preparation, including the selection of appropriate materials, the design and analysis of the antenna, and the compilation of this thesis.

This thesis is submitted as part of the requirements for obtaining an MSc degree at Haramaya University. A copy of the thesis will be stored in the Haramaya University Library, where it will be accessible to borrowers according to the library's regulations. I confirm that this thesis has not been submitted to any other institution for the purpose of earning any academic degree, diploma, or certificate.

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AUTOBIOGRAPHY

The author was born on January 18, 1992, in Toke Mugno, a town in the West Shoa Zone of the Oromia National State, Ethiopia. He attended Toke Mugno Primary School from 2000 to 2003, and then Ambo Addis Ketama Primary School from 2004 until he completed grade 8 in 2007. He continued his education at Ambo Secondary School from 2008 to 2009 and completed grades 11 and 12 at Ambo Preparatory School between 2010 and 2011.

After passing the National High School Leaving Examination, he enrolled at Haramaya University in October 2012 to study Electrical and Computer Engineering, specializing in Electronic Communication Engineering. He graduated on July 7, 2016, and subsequently started his own business. In October 2018, he began pursuing an MSc program in Communication System Engineering at Haramaya University.

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LIST OF ABBREVIATIONS

ADS	Advance Design System
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
DGS	Defected Ground Structure
FR4	Flame Retardant 4
GPS	Global Positioning System
HFSS	High-Frequency Structures Simulators
MIMO	Multiple Input Multiple-Output
MMIC	Microwave Monolithic Integrated Circuits
MPA	Microstrip Patch Antenna
MSA	Microstrip Antenna
PCB	Printed Circuit Board
PDMS	Poly dimethyl siloxane
PET	Polyethylene Terephthalate
RL	Return Loss
RMP	Rectangular Microstrip Patch
RF	Radio Frequency
RFID	Radio Frequency Identification
SLL	Low Side Lobe Level
UWB	Ultra-Wide Band
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
Wi-Max	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Recent advancements in wireless communication systems have underscored the importance of antennas, with a growing demand for high-performance, compact, cost-effective, multiband, and wideband solutions in both commercial and military sectors. Microstrip patch antennas (MPAs) have emerged as a compact option that meets these requirements effectively. The study focused on designing and analyzing a microstrip patch antenna array for 5G applications, aiming to enhance performance and efficiency in next-generation communication networks. Utilizing ANSYS HFSS software, the research sought to optimize design parameters to achieve high gain, wide bandwidth, and low cross-polarization levels suitable for 5G systems. The proposed antenna designs on RT duroid 5880, FR4, and Mica substrates at 28 GHz demonstrated promising characteristics in radiation pattern, impedance matching, and efficiency for 5G applications. These antennas exhibited low reflection coefficients and good impedance matching, with VSWR values approaching 1. Operating within the frequency range of 26.1 GHz to 28.0 GHz, bandwidths varied from 900 MHz to 3700 MHz, with FR4 configurations offering wider bandwidths. Observed gain values ranged between 7.49 dB and 12.82 dB, with higher gains seen in RT material configurations with Ellipse modification. Directivity values between 9.78 dB and 12.79 dB indicated the antennas' focused directional radiation. Efficiency levels ranged from 76.58% to 99.86%, with RT material and Reflector modification antennas showing superior efficiency. The RT material with Ellipse modification design outperformed others in terms of efficiency, gain, directivity, return loss, and VSWR. Conversely, FR4 with Reflector modification provided broader bandwidth but compromised on gain and directivity.

Keywords: 5G, Compact, FR4, RT duroid 5880, Mica, and Wideband.

1. INTRODUCTION

1.1 Background

The fifth-generation (5G) network is expected to greatly enhance communication capacity by leveraging the extensive millimeter wave spectrum. It is also expected to deliver data speeds up to 100 times faster than those of 4G. Materials with low dielectric constants are beneficial for improved radiation, although 5G demands high gain, increased directivity, broader bandwidth, and compact design. Meeting these performance goals introduces complex requirements for both network infrastructure and antenna design in 5G communication systems (Omar et al, 2019).

Most modern wireless communication applications require antennas with high performance, compact size, wide bandwidth, and multiband capabilities. The microstrip antenna (MSA) effectively meets these demands. First proposed in 1953, the microstrip antenna concept took nearly 20 years to become practical with the advent of printed circuit board (PCB) technology in the 1970s (Balanis et al., 2016). Numerous studies have examined printed antennas and arrays, known for their compact size, lightweight design, high-frequency compatibility, and versatile design options. The following section focuses on the design and analysis of a microstrip patch antenna, with a brief discussion of its key features. The analysis establishes the foundation for the proposed study. The types of structures under investigation are described, along with visualizations of the fields above and around the conducting surfaces. An expression for the resonant length is derived, highlighting its significance. Finally, the concept of mutual coupling is introduced and illustrated using a two-port antenna network.

1.1.1 The Microstrip Antenna and Mutual Coupling

A microstrip device comprises two flat conductive layers separated by a thin dielectric material. The upper conductive layer is usually connected to a power source, while the lower layer acts as a ground plane. In a microstrip patch antenna, the radiating patch is separated from the ground plane by a dielectric substrate with a thickness denoted as "d." As illustrated in Figure 1.1, the length (L) of the conductive patch corresponds to a substantial fraction of the source wavelength, making it a resonant antenna (Stutzman & Thilee, 2012). Due to its resonant nature, the antenna exhibits a narrow bandwidth and larger dimensions at frequencies below 1 GHz, making it more suitable for multi-band frequencies. The radiating patch and ground plane are typically made from metallic conductors like tin, nickel, silver, aluminum, copper, or gold. Various shapes such as rectangular, dipole, square, semicircular, circular, triangular, octagonal, annular ring, sectorial, and elliptical are used for the radiation patches, with rectangular and circular designs being the most common (Nawale & Zope, 2014).

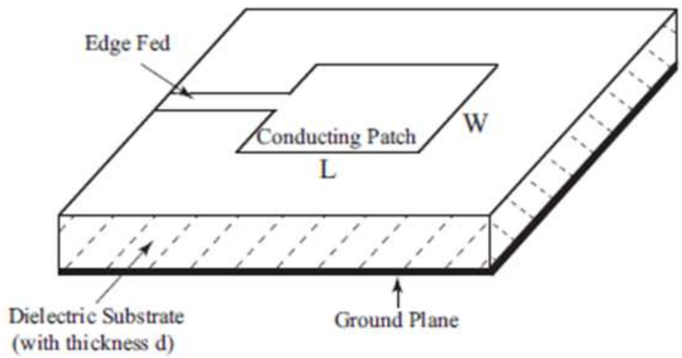


Figure 1.1: Microstrip patch antenna

The area that separates the ground plane from the conducting patch functions similarly to the area that separates an open transmission line from the ground plane. In the dielectric, this causes a standing wave. Figure 1.2 depicts the fields related to the standing wave between the ground plane and the conducting patch. It is evident that the bordering fields are equal in magnitude and 180 degrees out of phase at either end of the conducting patch. It is these bordering fields that are radiation-exposed to the area above the conducting patch.

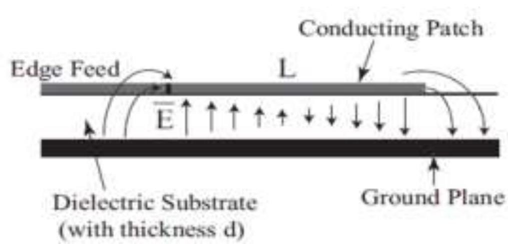


Figure 1. 2: Side view of microstrip antenna

Figure 1.3 displays the fields' top view. The conducting patch's electric field component is depicted in the same plane by the arrows at each end. It is evident that the fields are in phase, resulting in a broad side radiation pattern.

1.1.2 Feeding Techniques

An antenna is a passive device that requires an external power source for radiation, with its feeding technique playing a critical role in determining overall performance. Microstrip patch antennas can be fed using various methods, categorized into contacting and non-contacting types. In contacting methods, RF power is delivered directly to the radiating patch through a connecting element, with microstrip line feed and coaxial probe feed being the primary techniques. Conversely, non-contacting methods rely on electromagnetic field coupling to transfer power between the microstrip line and the radiating patch, utilizing approaches such as aperture coupling and proximity coupling (Karthik et al., 2018; Saraswati & Agrawal, 2016; Werfelli et al., 2017). The design under consideration employs a microstrip line feed, which introduces challenges in impedance matching. To overcome this, the microstrip line is inset into the patch, enhancing impedance matching and lowering input impedance for improved performance.

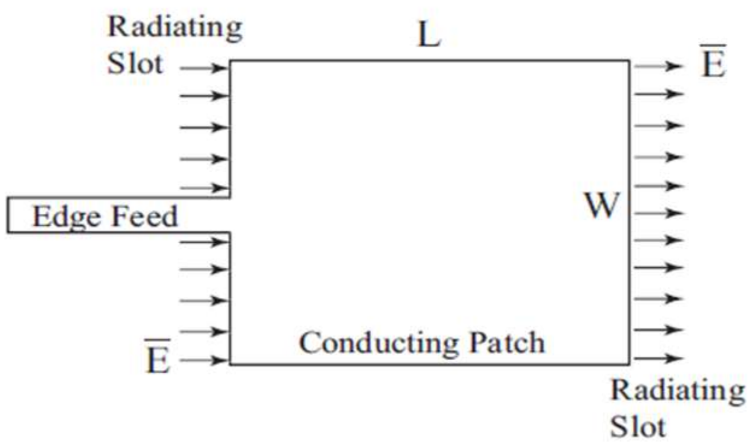


Figure 1. 3: Top view of microstrip antenna

Additionally, we can estimate the input impedance and resonant length for the edge-fed, microstrip transmission line antenna in Figure 1.1 at resonance. The patch's width (W) and length (L) are selected to provide a true input impedance on or near the operational frequencies. Similar to a dipole, the patch's effective length is extended by the fringing fields seen in Figure 1.3, although the resonant length L is only about 5λ. In order to attain resonance, the patch length must be slightly less than a half-wavelength. It has been demonstrated that the resonant length L is about equal to the substrate thickness significantly less than the source wavelength (Stutzman and Thilee, 2012):

$$L \approx 0.49\lambda_d = 0.49\frac{\lambda}{\sqrt{\varepsilon_r}} \quad 1.1$$

Where, ε_r the permittivity of the dielectric substrate¸ λ is the free space wavelength and ¸ λ_d is the wavelength in the dielectric substrate. Equation 1.1 demonstrates that the patch length must remain relatively constant; otherwise, input reactance will emerge at the feed location. Additionally, the input impedance at resonance can be approximated as (Stutzman and Thilee, 2012):

$$Z_A = 90 \frac{\varepsilon_r^2}{\varepsilon_r - 1} \left(\frac{L}{W}\right)^2 \Omega \qquad 1.2$$

Equations 1.1 and 1.2 are based on the assumption that the antenna in Figure 1.1 is isolated from any nearby sources or conductive objects; otherwise, the expressions become invalid. Intro is free from the influence of nearby sources or conductive objects; if this condition is not met, the equations no longer hold true. The introduction of another conductive object into the antenna's radiating region can alter the current distribution on the antenna, a phenomenon referred to as mutual coupling. In antenna arrays, mutual coupling can occur between adjacent elements, feed networks, or conductive structures such as enclosures and mounts. The voltage distribution among array elements depends on the feeding network (Kumar & Nagaveni, 2020; Sharma et al., 2017). A well-designed feeding network gathers all induced voltages into a single point. Elements can be fed by either a single or multiple lines in a feed network arrangement. For this design, a corporate-fed network with a quarter-wave transformer is used to match the patch element impedance with the 50-ohm input impedance, ensuring proper impedance matching for optimal performance. In particular, the mutual impedance Z_{mn} between two terminal pairs of antennas m and n is the open circuit voltage (V_{oc}) at the m^{th} terminal divided by the current supplied by the n^{th} terminal. This then gives;

$$Z_{mn} = \frac{V_m}{I_n} \qquad 1.3$$

1.2 Statements of the Problem

The input impedance of the driven element in an antenna array is expected to be significantly influenced by the mutual impedance with other driven and parasitic elements within the structure. This effect is particularly pronounced for elements that are positioned close to any driven elements. However, it is anticipated that selecting appropriate permittivity values for the anisotropic materials used in the array can help minimize this mutual impedance. Additionally, strategically placing the conductive elements on different anisotropic layers is expected to reduce coupling, thereby minimizing any negative impact on the overall performance of the antenna. In some cases, it may even be possible to reduce the actual surface area of the array without compromising performance by carefully selecting permittivity values and using the design flexibility to place driven elements on other anisotropic layers. The scope of this work primarily focuses on specific types of antennas, but the concepts explored here could be extended to various new areas of research. For example, the principles could be applied to newer frequency antennas, ultra-wideband (UWB) antennas, different types of arrays, and even materials like metamaterials.

Additionally, this research could be extended to address challenges in systems with many RFID tags nearby, where significant mutual coupling could directly impact power harvesting capabilities and read range. Exploring the use of anisotropic materials as substrates and superstrates for RFID tags is another promising area for future research..

1.3 Objectives of the Thesis

1.3.1 General objective

The main objective of this thesis is to design and analyze of microstrip patch array antenna for 5G applications to achieve multiband and high antenna gain.

1.3.2 Specific objectives

- To examine the existing methods of designing a microstrip patch antenna array.
- To design both single and multiple microstrip patch antenna elements using Rogers RT Duroid 5880, FR4, and Mica substrates.
- To assess the performance of both single and multiple microstrip patch antenna elements.
- To select and develop a numerical method for calculating input impedance and mutual coupling between multiple antenna elements.

1.4 Scope of the Thesis

This thesis focuses on the design, simulation, and analysis of individual antennas and antenna arrays utilizing microstrip patches. It also involves comparing the performance of these antennas to identify the optimal design among those proposed.

1.5. Significance of the Thesis

The rapid progress of 5G technology requires the creation of high-performance antennas capable of meeting the rigorous demands of next-generation communication systems. This thesis is important as it focuses on the design and analysis of a microstrip patch antenna array specifically designed for 5G applications. By concentrating on key performance factors such as high gain, broad bandwidth, and low cross-polarization, this research contributes to optimizing antenna design parameters critical for ensuring reliable and efficient 5G communication. The results of this study could significantly advance the development of compact, lightweight, and efficient antenna arrays suitable for integration into a wide range of 5G devices and infrastructure.

1.6. Organization of the Thesis

This thesis is structured into five chapters. Chapter One presents the study's objectives, problem statement, scope, and significance in the context of 5G applications. Chapter Two provides a review of essential antenna design principles, focusing on microstrip patch antennas and addressing the unique challenges posed by 5G. Chapter Three details the design parameters, methodology, and simulation process conducted using ANSYS HFSS. Chapter Four analyzes the simulation results, evaluating performance metrics and comparing various design configurations. Finally, Chapter Five summarizes the findings, discusses their implications for 5G technology, and offers suggestions for future research and advancements.

2. LITERATURE REVIEW

2.1 Literature Survey

This section provides an in-depth review of the technologies and design approaches employed by researchers in developing microstrip patch antennas. In a study by (Anjum, 2020) a printed monopole antenna was designed and simulated, demonstrating efficient operation across three frequency bands. The antenna operates within a frequency range of 2.4 GHz to 7 GHz and features compact dimensions of 41 x 44 x 1.6 mm^3. Its resonance frequencies are observed at at 2.4 GHz, 5.338 GHz, and 6.91 GHz. At 2.4 GHz, the antenna achieved a return loss of -20.481 dB and a VSWR of 1.22, while at 5.338 GHz, it recorded a return loss of -19.576 dB and a VSWR of 1.2368.

Microstrip patch antenna arrays have been developed for applications in WLAN and WiMAX, as demonstrated by (Elkwash, Derbal, & Elmabrok, 2017). Their work focused on designing and fabricating a 16-element rectangular microstrip patch array antenna operating in the S-band frequency range. Simulations conducted using ADS software revealed return losses of -21.7 dB at 2.45 GHz and -19.6 dB at 2.54 GHz, with the antenna achieving a gain of 13 dB. The antenna's resonance frequency, ranging from 2.378 GHz to 2.594 GHz, confirms its suitability for S-band applications such as WLAN and WiMAX.

Similarly, (Errifi, Baghdad, Badri, & Sahel, 2015) designed and simulated rectangular microstrip patch array antennas using HFSS software, comparing the performance of arrays with 2, 4, 8, and 16 elements to a single patch antenna operating at the same frequency. To optimize radiation performance, low dielectric constant substrates were used, with the RT-duroid substrate significantly improving gain, directivity, and return loss. The antennas, fed using a power divider and a quarter-wave transformer, were designed to operate at a frequency of 10 GHz.

Hariyadi, Aliyuddin, & Wahyu, (2020) Conducted their investigation in two distinct phases. The initial phase centered on optimizing the design of a microstrip antenna array. In the subsequent phase, metamaterials were incorporated into the antenna array, with simulations performed using CST Studio Suite to improve gain and bandwidth. The microstrip antenna array was fabricated on an FR-4 substrate, characterized by a dielectric constant of 4.35 and a thickness of 1.6 mm. The results demonstrated that the metamaterial-based microstrip antenna array achieved superior bandwidth compared to a conventional microstrip antenna array.

Husna, Jamlos, Mustafa, & Idrus, (2020)proposed a high-gain, circularly polarized 2×1 rectangular microstrip array antenna designed for wide communication applications. The antenna, measuring 130×80 mm^2, comprises two microstrip patch elements arranged in an array. It is constructed on a Rogers RT 5880 substrate, featuring a dielectric constant of 2.1 and a thickness of 1.53 mm, and is fed via a microstrip transmission line with a full ground plane. At the target frequency of 5.8 GHz, the array antenna achieved a gain of 10.77 dB and a return loss of -24.63 dB.

Johari, Jalil, Ibrahim, & Mohammad, 2018) introduced the design of a microstrip patch antenna array operating at the core frequency of 28 GHz within the 28 GHz waveband. The 2×2 patch antenna array, composed of four uniformly distributed rectangular patch elements, features a compact footprint of 26.51×20.37 mm^2. The design employs the inset feed technique to ensure impedance matching between the 50Ω microstrip feed line and the radiating patch. The antenna achieved a gain of 8.393 dB, surpassing other antennas such as the CRLH TL CPW antenna (2.99 dB gain), the wideband antenna (7.1 dB gain), and the broadband elliptical-shaped slot antenna (3.7 dB gain). Additionally, it demonstrated a directivity of 10.13 dB and an efficiency exceeding 80%, highlighting its potential for 5G wireless networks and applications.

The design of a 16-element rectangular patch array antenna for 5G applications is presented in this study (Jyothika, Shekar, Krishna, & Rahman, 2020). It provides a reasonable transfer speed of roughly 28 GHz. The Rogers RT/ Duroid 5880 substrate ($\varepsilon r = 2.2$, $\tan\delta = 0.00009$) has a rectangular fix receiving wire that could be the most important part of this course of action. The rectangular fixed antenna measures 3.58 inches long by 4.52 inches wide. This paper focuses on the design and fabrication of a rectangular microstrip fixed antenna featuring an inset feed. An inset feed straightly polarized rectangular patch antenna with a four-element array is developed using a novel molecular swarm optimization method based on HFSS. The single fixed antenna operates within the frequency range of 26.5 GHz to 28 GHz, achieving a gain of 7.8 dB. The gain is further enhanced in the 16-element antenna array configuration.

The design and analysis of the rectangular microstrip patch (RMP) antenna and its linear arrays are presented in the work (Kaushal & Mishra, 2015). Directivity gain and bandwidth are used to evaluate the performance utilizing various dielectric substrate materials. The same RMP antenna is arranged linearly and power divider circuits are used to create 2x1 and 4x1 RMP antenna arrays that improve bandwidth, directivity, and gain. The performance evaluation of the RMP antenna is conducted by comparing its linear array with the simulated results. The designs utilize various substrates, including Rogers RT Duroid 6002 (dielectric constant of 2.4), Rogers RT Duroid 5880 (dielectric constant of 2.2), and FR4 epoxy (dielectric constant of 4.4).

In this study (Khalifa, Sahar, Ramli, & Islam, 2019), a 12-element antenna array with circular polarization is designed for a high-gain GPS. The circularly polarized antenna is ideal for use with a range of wireless devices, including the GPS, which operates at 1.27 GHz with an angle of reception (AR) of less than 3 dB between 82o and 140^{o}. The antenna consists of twelve parallel-connected primary radiation patches and is designed on a Rogers RT 5880 substrate, featuring a thickness of 0.787 mm and a dielectric constant (εr) of 2.2. Operating in the L-band, the antenna has a resonance frequency of 1.27 GHz and is energized through an inset feed line.

This study by (Lamminen, Säily, Ala-Laurinaho, Cos, & Ermolov, 2020)details the design, fabrication, and characterization of a 16-element antenna array and a wide-band cavity-backed aperture-coupled patch antenna developed for D-band applications on a multilayer printed circuit board (PCB). To investigate line losses in the D-band, microstrip line and grounded coplanar waveguide (GCPW) transmission lines are also designed and evaluated. The test structures are fabricated using semi-additive processing (SAP) of conductors on a multilayer substrate, leveraging PCB technology. The highest gains recorded are 7 dBi for a single antenna and 14 dBi for the 16-element array at 143 GHz, with the antenna exhibiting an input-matching bandwidth of 20 GHz.

In this study, (Maharjan & Choi, 2020), a corporate-series technique-fed, four-element microstrip patch array antenna is proposed. This study contrasts the suggested design with four-element microstrip antennas supplied solely by corporate and series feeds. With two insets and slots on both sides of the patch, rectangular microstrip patch components are used in all three antenna configurations. Yagi components three direction elements and two reflector elements complement the patch elements. The research compares simulation findings and finds that antennas with a combination corporate-series feeding strategy, such as a four-element array antenna, outperform antennas with a series or corporate feeding network alone. With a broad frequency spectrum of 25.04 to 30.87 GHz and a gain of 9.5dB, the suggested corporate-series fed antenna performs better. The antenna has an end-fire radiation pattern.

In this study by (Omer, 2019),a 28 GHz rectangular microstrip patch antenna is designed and simulated. The compact dimensions of the patch are 6.285 x 7.235 x 0.5 mm. The proposed antenna achieves a bandwidth of 847 MHz, a gain of 6.63 dB, and an efficiency of 70.18%, with a resonance frequency of 27.954 GHz and a return loss of -13.48 dB. The matching between the 50

Ω microstrip feedline and the radiating patch is accomplished using an inset feed transmission line technique. The design employs a Roger RT Duroid 5880 substrate with a dielectric constant of 2.2. The antenna's geometry is determined using Computer Simulation Technology Microwave Studio, and the simulation results are presented and analyzed.

In their study, (Patel, Kuchhal, Lal, & Mishra, 2017)propose the use of rectangular microstrip patches to create a high-gain, narrow-band array. Each element of the array features a rectangular shape. The materials used as substrates are FR-4 and Rogers-3006, with heights of 1 mm and dielectric constants of 4.4 and 6.51, respectively. The feeding mechanism employed is a microstrip line feed. The design of the 8x1 patch array antenna using Rogers-3006 demonstrates superior performance in terms of antenna gain compared to the FR-4 substrate for X-band applications, specifically at a frequency of 10 GHz. The primary application of this patch array is intended for use as a sensor in "Intrusion Detection."

In their study, (Prakasam, LaxmiKanth, & Srinivasu, 2020) present the design and simulation of a two-by-one Rectangular Micro Strip Patch Array (RMSPA) antenna utilizing corporate feed network systems for S-band applications at a frequency of 2.45 GHz. The proposed antenna features a substrate with a thickness of 1.65 mm and a dielectric constant of 4.5. The primary objective of this research is to simulate and develop RMSPA antennas using CST MWS software while evaluating the performance of the two-element patch array antennas at 2.45 GHz. Additionally, the study examines various parameters of the two corporate feed systems, including the reflection coefficient (return loss), bandwidth, Voltage Standing Wave Ratio (VSWR), directivity, gain, and radiation pattern.

A microstrip patch array antenna operating at a frequency of 28 GHz has been developed, utilizing Rogers Duroid RT5880 as the substrate material. This substrate features a copper thickness of 0.254 mm and a dielectric constant (εr) of 2.2. The antenna design achieved an impressive return loss of -52.522 dB at a frequency of 28.08 GHz, attributed to optimal parameter selection. Additionally, the antenna boasts a significant gain of 21.1 dBi and reaches a bandwidth of 1120 MHz (Rahim, Ibrahim, Kamaruddin, Zakaria, & Hassim, 2018)

A rectangular slotted microstrip patch array antenna has been developed for applications in wireless local area networks (Ramya, Supratha, & Robinson, 1702-1705). The study examines the impact of key design features, such as radiation pattern, Voltage Standing Wave Ratio (VSWR), and return loss, across various configurations including single patch, 1x2, 1x4, and 1x8 patch array antennas. Among these configurations, the 1x4 patch array demonstrates the most favorable performance. The dimensions of this array antenna are 143 mm by 71 mm, and it incorporates patch splits and slots to enhance bandwidth. The 1x4 array is designed to resonate at 2.4 GHz, achieving a VSWR of 1.0233 and a return loss of -33.6878 dB.

This paper explores the performance of two-element antenna arrays both with and without electromagnetic band gap (EBG) structures (Rao, Vani, & Hunagund, 2019). The design of the antenna arrays is conducted using Mentor Graphics IE3D software, with measurements taken using a vector network analyzer. The dielectric substrate employed in the antenna construction is FR-4 glass epoxy. The incorporation of EBG structures in the ground plane of the microstrip antenna array significantly reduces mutual coupling, improving it from -17.83 dB in the traditional array to -35.05 dB. Additionally, the proposed microstrip array achieves a bandwidth of 25.18%, which is notably higher than the 2.35% bandwidth produced by standard microstrip antenna arrays. The EBG-structured antenna array resonates at a fundamental frequency of 3.31 GHz, enabling a virtual size reduction of 40.14%.

This paper presents a dual-band microstrip patch array antenna designed for LTE applications in Malaysia (Salisu, Elfergani, Mohammed, Anuhu, Abd-Alhameed, & Rodriguez, 2020). The dimensions of a single-element antenna were first established using a transmission line model, targeting resonance frequencies of 1.8 GHz and 2.6 GHz. Subsequently, two-element and four-element antenna arrays were developed to enhance directivity. Each antenna element is connected through a microstrip feed line with a 3dB splitter. Simulations were conducted using CST Microwave Studio, revealing that the 4x1 array configuration yielded the most favorable outcomes, achieving directivities of 11.2 dB at 1.8 GHz and 12.9 dB at 2.6 GHz.

This research introduces a 4x1 element circular phase array of inset-fed rectangular patch antennas operating in the millimeter wave range of 24.81 GHz to 33 GHz (Shah and Singh, 2020). The array features an edge-coupled parasitic patch design that facilitates dual resonance and offers a wide impedance bandwidth. To reduce unwanted side lobe radiation, the array incorporates a ring-shaped sequential rotation feeding line. The antenna maintains a bandwidth of 26% within the specified frequency range, achieving a return loss of -10 dB to -18.64 dB. Notably, a return loss of -18.64 dB is recorded at 29.09 GHz, with a voltage standing wave ratio (VSWR) of less than 1.85 across the frequency range. The antenna array delivers a gain of 10.14 dB.

This study presents the design and analysis of a stacked rectangular array antenna featuring various feeding mechanisms (Shukla & Chaturvedi, 2020). A rectangular microstrip patch antenna with a rectangular slit is created and modeled using HFSS software. The study explores both line and coaxial feeding systems for the configurations of 1x1, 1x2, and 1x3 stacked antennas. These antennas are intended to operate at a frequency of 2.8 GHz and are fabricated on FR-4 epoxy substrates with a dielectric constant of 4.4. The findings indicate that a stacked antenna array with a narrow slot outperforms a single antenna in effectiveness. The performance characteristics, including radiation pattern, gain, directivity, voltage standing wave ratio (VSWR), and return loss, are evaluated using the HFSS tool.

The study by (Sonanki, 2020) focusing on configurations with one, two, and four elements operating at a frequency of 12 GHz. The substrate utilized for both the microstrip line and the patch is RT Duroid 5880, featuring a thickness of 1.56 mm and a dielectric constant of 2.2. Simulation results reveal that the four-element array configuration significantly enhances gain and directivity by 120% compared to a single-element design. Furthermore, the impedance bandwidth shows an impressive increase of 478% when compared to the single-element configuration.

Wang, Kedze, & Park, (2018) present a 4x4 microstrip patch array antenna designed to achieve low side lobe levels (SLL) and high gain. This antenna utilizes a feed network that combines parallel and series configurations with varying power distribution ratios. To optimize the power distribution, the characteristic impedance of the feed network is fine-tuned using a series of quarter-wavelength impedance transformers. The resulting design boasts an impedance bandwidth of 220 MHz, with a return loss below -10 dB, yielding a fractional bandwidth of 2.1%. At a frequency of 12.5 GHz, the antenna achieves a gain of 18.2 dBi and records SLLs of -28.0 dB and -26.5 dB in the x-z and y-z planes, respectively.

This work (Zoukalne, Chaibo, & Khayal, 2020) proposes the design of a microstrip patch antenna array with two radiating elements resonating at 3.6 GHz for a 5G C-band access point application. The suggested antenna is made for the Rogers RO4350 (tm) substrate, which has a thickness of 3.54 mm and a dielectric constant of 3.66 εr. Three slots are included in the antenna design; two are located on the radiating elements and one is on the power line. The planned antenna has a gain of 9 dBi and a bandwidth of 200MHz when simulated using HFSS.

2.2 Antenna Arrays

An antenna array consists of two or more antennas working together to transmit and receive radio waves. By interconnecting these individual antennas, the overall performance of the radiating system is enhanced. Microstrip antenna arrays, in particular, are widely utilized to boost the efficiency, directivity, and gain of communication systems. This enhancement is crucial because a single antenna element often generates a broad radiation pattern with wide beam angles, which may not be ideal for point-to-point communication that necessitates more directional antennas. Additionally, a single antenna element often results in suboptimal bandwidth, efficiency, and gain. These limitations make single-element antennas less desirable. Using an array configuration of antennas addresses these issues (Singh & Gupta, 2013).

The overall radiation pattern of an antenna array can be influenced by five factors:

- The arrangement of the array elements, such as rectangular, circular, triangular, or hexagonal lattices..
- Distance between elements in an array.
- Radiation pattern of individual elements.
- The amplitude of excitation applied to each element.
- The phase of excitation applied to each element.

2.3 Feeding Network Configurations

In microstrip arrays, element feeding can be implemented using either a single line or multiple lines within a feed network. The feeding methods are broadly categorized into corporate feed networks, series feed networks, corporate-series feed networks, and series-parallel feed networks (Wang et al., 2018). Each method offers unique characteristics and applications, influencing key performance metrics such as gain, bandwidth, and radiation pattern.

2.3.1 Series Feed Network

A series feed network typically consists of a continuous transmission line, from which energy is incrementally coupled to individual elements positioned along the line. When the feed line ends with a matched load, this configuration forms a traveling wave array. In such arrays, the radiation pattern can be customized by modifying the dimensions (width and height) of the individual patch radiators and by optimizing the feeding network design (Errifi et al., 2015; Singh and Gupta, 2013). This approach enables precise control over the array's radiation characteristics and enhances overall antenna performance.

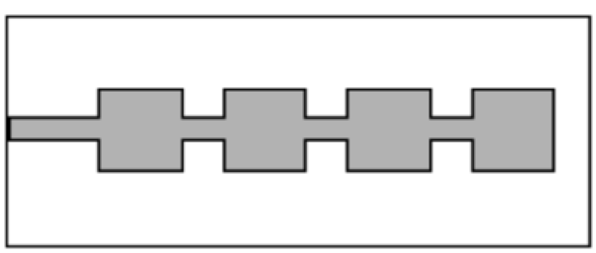


Figure 2. 1 Series feed network

2.3. Corporate 2 Feed Network

The corporate feed is the most commonly used parallel feed configuration. In this setup, power is evenly distributed at each junction, ensuring uniform aperture distribution. To achieve a tapered distribution across the array, alternative power division ratios can be employed. However, this approach has some drawbacks, including the need for long transmission lines to connect radiating elements to the input port. These extended lines can result in significant insertion losses within the feed network, which may reduce the array's overall efficiency. To address these issues, a combination of series and corporate feeds—known as the series-corporate feed—is often used in array antennas, offering the benefits of both feeding methods (Errifi, Baghdad, Badri, & Sahel, 2015; Patel, Kuchhal, Lal, & Mishra, 2017; Singh & Gupta, 2013).

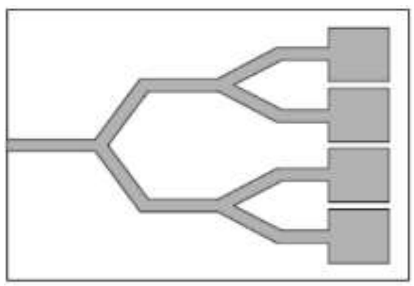


Figure 2. 2 Corporate feed network

2.4 Application of Microstrip Patch Antenna

2.4.1 Global Positioning System Applications

Modern global positioning systems commonly use microstrip patch antennas made with high-permittivity sintered materials. Due to their compact design and circular polarization, these antennas tend to be costly. However, their application is widespread, with millions of GPS receivers expected to assist the public in accurately locating land vehicles, aircraft, and marine vessels (Kumar B. S., 2018).

2.4.2 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) technology is extensively used across industries such as mobile communication, logistics, manufacturing, transportation, and healthcare. Depending on the specific application, RFID operates within frequency ranges from 30 Hz to 5.8 GHz. An RFID system consists of two key components: a tag (or transponder) and a transceiver (or reader), which collaborate to enable object identification and communication. In mobile communication, RFID facilitates contactless payments and access control. In logistics, it enhances inventory management by enabling real-time tracking of goods, improving efficiency and accuracy in supply chain operations. Manufacturing benefits from RFID through improved production processes and quality control. In transportation, RFID facilitates automatic toll collection and smart ticketing, while in healthcare, it enhances patient care and hospital management by tracking equipment and ensuring accurate patient identification (Karhana & kumar, 2017 and Pujar, Dr.Jagadeesh, & Malagitti, 2019).

2.4.3 Worldwide Interoperability for Microwave Access (WiMax)

WiMax, based on the IEEE 802.16 standard, is a wireless communication technology capable of providing data speeds of up to 70 Mbps and a theoretical coverage range of up to 30 miles. Microstrip Patch Antennas (MPAs) can generate signals at three distinct frequencies 2.7 GHz, 3.3 GHz, and 5.3 GHz making them well-suited for integration into devices that support WiMax communication. (Karhana & Kumar, 2017; Pujar et al., 2019).

2.4.4 Radar Application

Radar systems, which are used to detect moving targets like people and vehicles, require antennas that are low profile and lightweight. Microstrip antennas are ideal for this purpose. The use of photolithography in fabricating microstrip antennas allows for mass production with consistent performance, all at a lower cost and in less time compared to traditional antennas (Kumar, 2018, Indrasen and Tripathi, 2011).

2.4.5 Rectenna Application

A rectenna is a unique type of antenna engineered to convert microwave energy directly into DC power. It consists of four primary components: the antenna, a pre-rectification filter, a rectifier, and a post-rectification filter. To optimize rectenna performance, it is crucial to design antennas with high directivity, which ensures efficient energy transfer over long distances. Enhancing the antenna's electrical size is essential to improve this directivity, thereby enabling the rectenna to transmit DC power wirelessly over greater distances (Kumar, 2018; Indrasen & Tripathi, 2011).

2.4.6 Telemedicine Application

In telemedicine applications, a wearable microstrip antenna operating at 2.45 GHz is well-suited for Wireless Body Area Networks (WBAN). This proposed antenna provides higher gain and an improved front-to-back ratio compared to alternative designs. Additionally, it features a semi-directional radiation pattern, which is advantageous over omnidirectional patterns. The semi-directional design reduces unnecessary radiation exposure to the user's body while effectively supporting both on-body and off-body communication needs (Indrasen & Tripathi, 2011).

2.4.7 Medicinal applications of patch

Microwave energy is recognized for its effectiveness in inducing hyperthermia for treating malignant tumors. The radiator employed in this application must be lightweight, easy to handle, and durable, all of which are characteristics of the patch radiator. Initial designs of microstrip radiators for hyperthermia treatment incorporated printed dipoles and annular rings, specifically tailored to operate within the S-band frequency range (Indrasen & Tripathi, 2011).

2.4.8 Mobile and satellite communication application

Mobile communication systems demand antennas that are compact, affordable, and unobtrusive, which are key attributes of microstrip patch antennas. These antennas are designed to fulfill the unique needs of mobile communication. In satellite communication, where circularly polarized radiation patterns are essential, square or circular microstrip patches can be used to generate these patterns. These patches can incorporate one or two feed points, adding flexibility for a range of communication applications.

3. MATERIALS AND METHODS

3.1 Properties of Interest in Microstrip Antenna

When examining microstrip antennas, several key properties become significant, including input impedance, resonant frequency, bandwidth, gain, efficiency, far-field patterns, and near-field patterns. Additionally, if the antenna is situated near another conductor, mutual impedance and the reflection coefficient S11 also come into play. This proposed research aims explore these aspects by evaluating the antenna's performance parameters, such as radiation pattern, efficiency, directivity, gain, bandwidth, return loss, and Voltage Standing Wave Ratio (VSWR), among others.

Antenna efficiency, also known as radiation efficiency, is the ratio of the power radiated by the antenna to the total input power supplied to the antenna. It can be mathematically defined as:

$$\eta = \frac{P_{rad}}{P_{in}} \qquad 3.1$$

Where, η is radiation efficiency, P_{rad} is total radiated power and P_{in} is input power.

The directivity of an antenna is defined as the ratio of the peak radiation intensity in a specific direction to the average radiation intensity over all directions. This concept highlights the antenna's ability to concentrate energy in a particular direction, as opposed to its overall radiation performance (Balanis et al., 2016).

$$D = 4\pi \frac{U}{p_{rad}} \qquad 3.2$$

Where D is directivity and U is radiation intensity.

For a lossless antenna, the antenna gain is equal to its directivity. In this case, when the antenna has no losses, the gain directly reflects its ability to direct energy toward a specific direction, similar to how directivity quantifies the concentration of radiation intensity in that direction (Balanis et al., 2016).

$$\text{Gain(G)} = \frac{4\pi \text{ Radiation Intensity}}{\text{Total Input Accepted Power}} \qquad 3.3$$

However, when accounting for losses, the relationship between antenna gain (G) and directivity (D) is influenced by the antenna's efficiency. In this context, the gain can be expressed as a function of directivity multiplied by the efficiency, reflecting how losses impact the overall performance of the antenna.

$$G = \eta D \quad 3.4$$

Bandwidth is calculated as:

$$BW = \frac{f_h - f_l}{f_c} * 100\% \quad 3.5$$

Where, f_c is Center frequency, f_l is low frequency and f_h is high frequency.

The RL is given as:

$$RL = -20\log|\Gamma| \quad 3.6$$

If the RL indication is lower than -10 dB it means this matching is good.

Where, Γ is the reflection coefficient and RL is return loss.

$$\Gamma = \frac{V_i}{V_r} = \frac{Z_{in} - Z_s}{Z_{in} + Z_s} \quad 3.7$$

Where, V_i is amplitude of incident is wave, V_r is amplitude of reflected wave, Z_{in} input impedance and Z_{in} is transmitter impedance.

The VSWR can be expressed as;

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad 3.8$$

3.2 Design Parameters of Microstrip Patch Antenna

Microstrip patch array antennas are engineered to provide superior performance compared to single patch antennas, particularly in terms of bandwidth, return loss, and gain. The design process for a patch array antenna begins with determining the dimensions of the patch, substrate, and feeding line. Key parameters for this design include the operating frequency, the type of dielectric material, and the height of the dielectric substrate (Hailamariam et al., 2019; Rashid et al., 2018). The antenna is specifically designed to operate at a frequency of 28 GHz. The selected dielectric materials for the antennas include Rogers RT Duroid 5880, which has a dielectric constant of 2.2, FR-4 with a dielectric constant of 4.4, and mica with a dielectric constant of 5.7. The height of the dielectric substrate is set at 0.5 mm, with the width and length of the designed antenna being directly influenced by this height.

3.3 High-Frequency Structural Simulator (HFSS) Software

ANSYS HFSS is a widely used commercial solver that employs the Finite Element Method (FEM) to analyze electromagnetic structures. It includes key optimization tools for antenna engineers, allowing for precise adjustments to antenna parameters. Operating within a three-dimensional FEM environment, HFSS computes solutions for each frequency separately using a frequency domain approach. This method involves dividing the model space into small finite elements, like triangles or tetrahedra, and representing the field in each subdomain using local functions. The scattered field is then expressed as a sum of known basis functions with unknown coefficients. HFSS accommodates various boundary conditions, with radiation and Perfect Electric Conductor (PEC) boundaries being the most common. It offers detailed vector and scalar representations of electric (E), magnetic (H), and current (J) fields, providing valuable insights during simulations. The software transforms Maxwell's equations into matrix equations, which are solved using numerical methods. The antenna design was analyzed using ANSYS HFSS, a highly regarded tool in the industry for its powerful drawing and design capabilities.

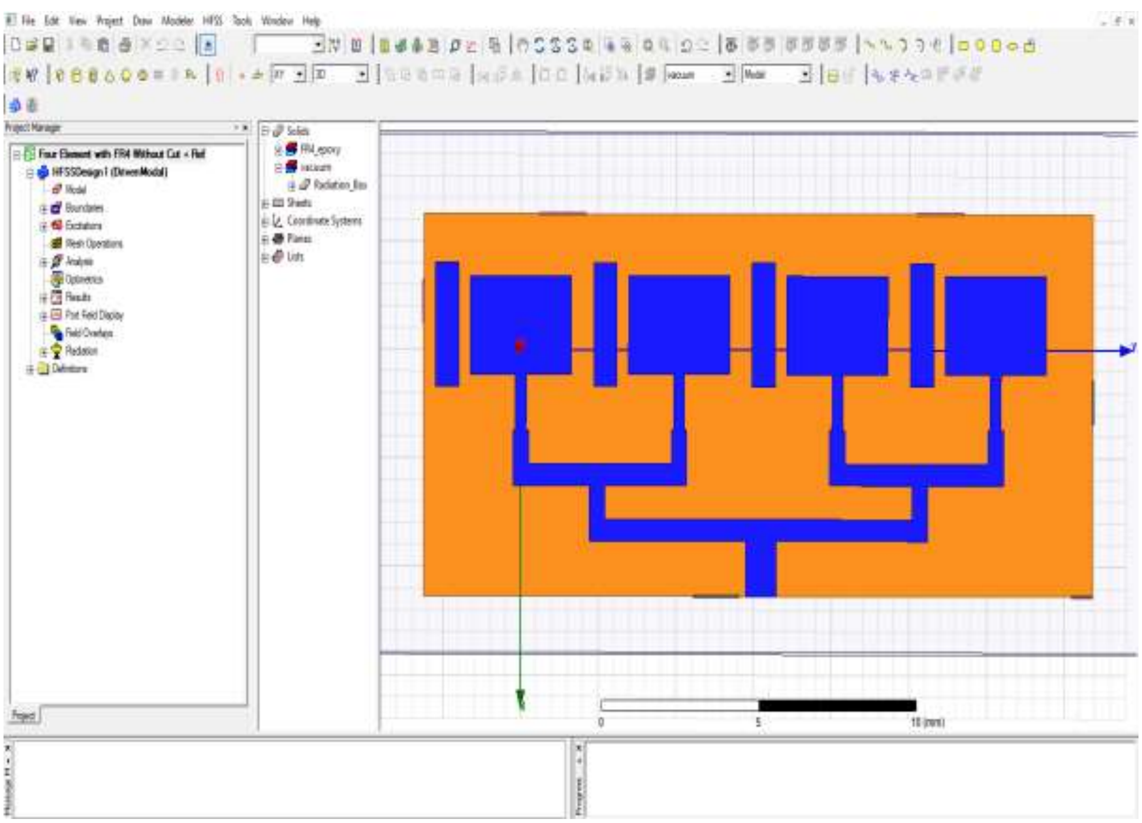


Figure 3. 1 ANSYS High-Frequency Structural Simulator (HFSS)

3.4 Design Methodology

The flow chart below outlines the methodology employed in designing the thesis work.

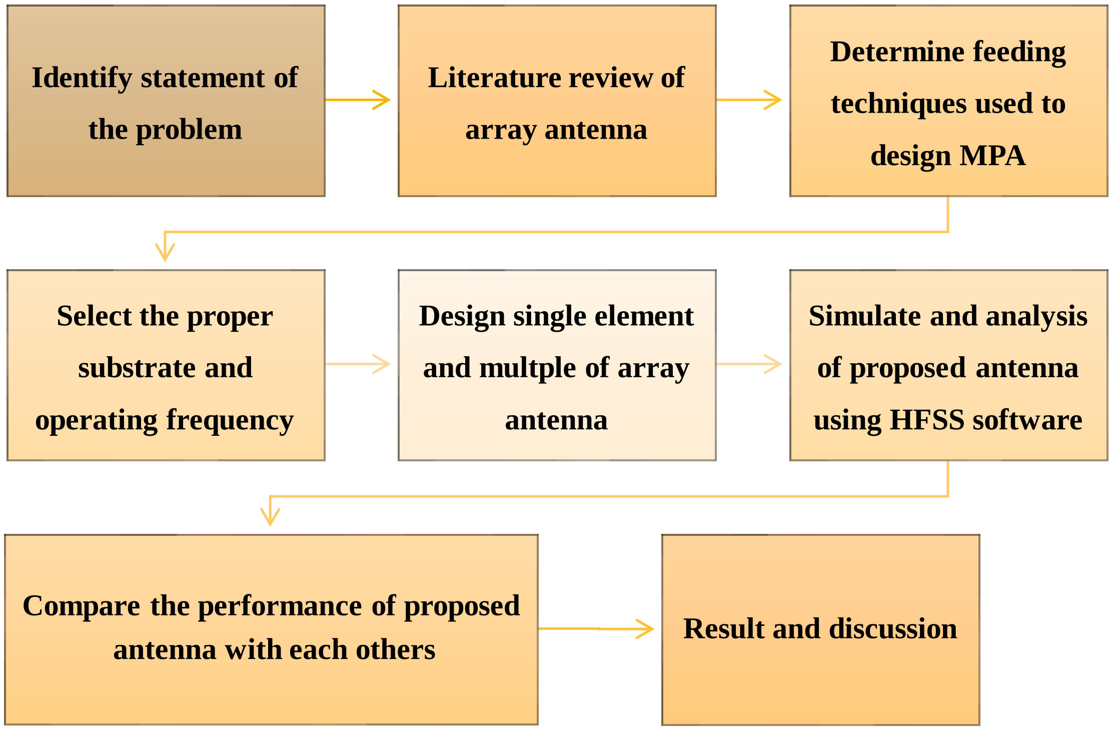


Figure 3. 2 Flow Diagram of Methodology

3.5 Design of Single Element of Microstrip Patch Antenna

The antenna was first designed as a single element utilizing a standard rectangular patch microstrip antenna. Equations listed below can be used to compute an antenna's dimensions, which describe its length (L) and width (W) at a certain operating frequency. The proposed antennas are design on Roger RT duroid 588 [$\varepsilon_r = 2.2$ and $h = 0.5$mm], FR4 [$\varepsilon_r = 4.4$ and $h = 0.5$mm] and Mica [$\varepsilon_r = 5.7$ and $h = 0.5mm$] substrate at 28 GHz operating frequency. The dimensions of an antenna, specifically its length (L) and width (W) for a specified operating frequency, can be determined using the equations provided below:

1. The width (w) of the patch can be calculated as

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{(\varepsilon_r+1)}} \qquad 3.9$$

Where c is the free space velocity of light; ε_r is the dielectric constant of the substrate and fr is the antenna design frequency.

2. The effective dielectric constant (ε_{reff}) can be determined by

$$\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad 3.10$$

3. The length of the radiated patch has been increased at both ends by a distance ΔL, which is determined empirically by the following expression.

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+1)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad 3.11$$

4. The length of a patch is calculated through the formula given below:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad 3.12$$

5. The width of the ground plane (w_g)

$$w_g = 6h + w \quad 3.13$$

6. The length ground plane (L_g)

$$L_g = 6h + L \quad 3.14$$

In this design, the dimensions of the ground plane's length and width are made equal due to the use of quarter-wave transmission line feeding techniques.

7. Quarter wave transmission line length is given by equation

$$l_t = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_r}} \quad 3.15$$

Where, $\lambda_0 = \frac{c}{f_r}$

8. Transconductance of the Patch

$$G_e = 0.00836\frac{W}{\lambda_0} \quad 3.16$$

9. The edge impedance of the patch is given by the equation

$$R_{in} = \frac{1}{2G_e} \quad 3.17$$

10. The characteristic impedance of a quarter-wave transmission line can be expressed using the following equation.

$$Z_t = \sqrt{Z_0 * R_{in}} \quad 3.18$$

11. Inset length of the patch for inserting microstrip feed line

$$Y_o = 10^{-4}(0.001699\varepsilon_r{}^7 + 0.13761\varepsilon_r{}^6 - 6.1783\varepsilon_r{}^5 + 93.187\varepsilon_r{}^4 - 682.69\varepsilon_r{}^3 + 2561.9\varepsilon_r{}^2 - 4043\varepsilon_r + 6697)\frac{L}{2} \quad 3.19$$

12. Feed line width

$$W_f = \frac{2h}{\pi}\left[(\beta - 1 - \ln(2\beta - 1)) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(\beta - 1) + 0.39 - \frac{0.69}{\varepsilon_r}\right)\right] \quad 3.20$$

Where $\beta = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$, Z_0 is 50 ohm.

13. Inset width of the cut or gap (W_c)

$$W_c = \frac{c*46.5}{f_r*\sqrt{2\varepsilon_{reff}}} \quad 3.21$$

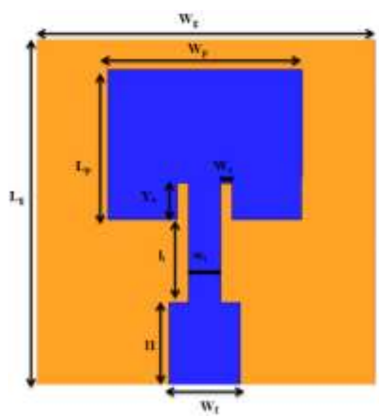


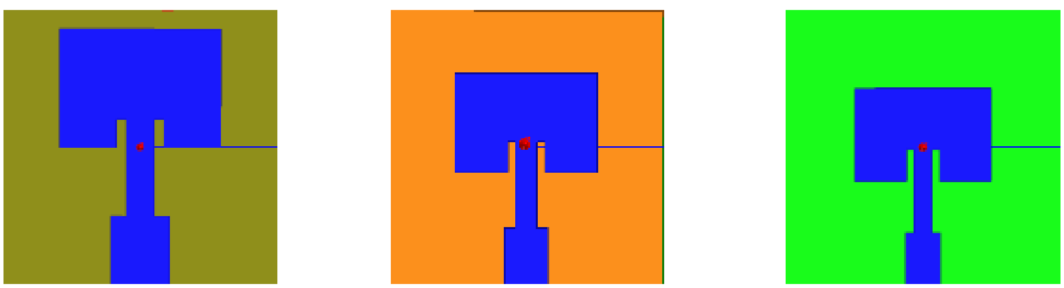
Figure 3. 3 Rectangular Microstrip Patch Antenna

3.6 Design of Single Element Microstrip Patch Antenna Array

The patch antenna offers benefits like being low-profile, lightweight, easy to fabricate, and adaptable to mounting positions. However, its drawbacks include narrow bandwidth, low gain, and limited directivity. To overcome these limitations, a hybrid microstrip patch array antenna can be designed. Microstrip patch array antennas offer advantages such as higher gain, wider bandwidth, improved directivity, and enhanced efficiency, achieving various functions that a single element cannot (Hailamariam et al., 2019; Rashid et al., 2018). The design was implemented using Ansoft HFSS software, featuring different configurations: a microstrip patch alone, with a reflector, with a director, with both a reflector and a director, and with a reflector and two directors to demonstrate end-fire radiation behavior.

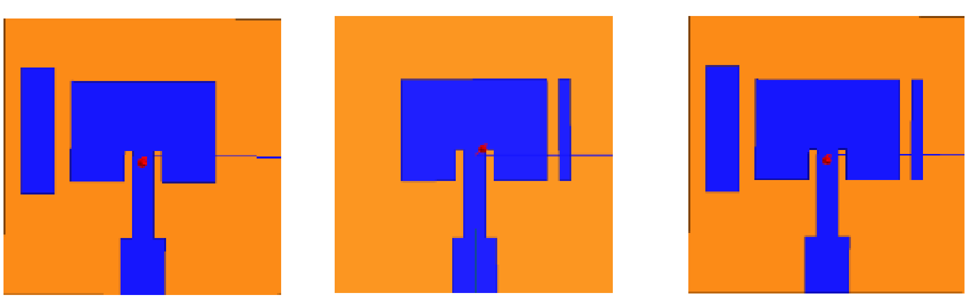
Table 3. 1 Design Parameters of Rectangular Microstrip Patch Antenna

Parameters	Value		
	RT-duroid 5880	**FR 4**	**Mica**
Frequency of operation, f_r	28 GHz	28 GHz	28 GHz
The dielectric constant, ε_r	2.2	4.4	5.7
Substrate height, h	0.5 mm	0.5 mm	0.5 mm
Length of ground plane, L_g	7.24 mm	6.26 mm	5.94 mm
Width of ground plane W_g	7.24 mm	6.26 mm	5.94 mm
Length of patch, L_p	3.14mm	2.27 mm	2.0 mm
Width of patch, Wp	4.26 mm	3.26 mm	2.94 mm
Transmission line length, l_t & l_1	1.8 mm	1.28mm	1.12mm
Feed line width, Wf	1.54 mm	1.0mm	0.75mm
Feed line width quarter wave, W_t	0.75 mm	0.5mm	0.38mm
Inset length of the patch, y_o	0.75 mm	0.69 mm	0.67mm
Width of inset cut or gap, w_c	0.25 mm	0.18mm	0.16mm
Wavelength, λ	7.2 mm	5.1mm	4.5mm



a. Single element patch of RT b. single element patch of FR 4 c. single element patch of mica

Figure 3. 4 Structure of single element microstrip patch antenna for different substrate



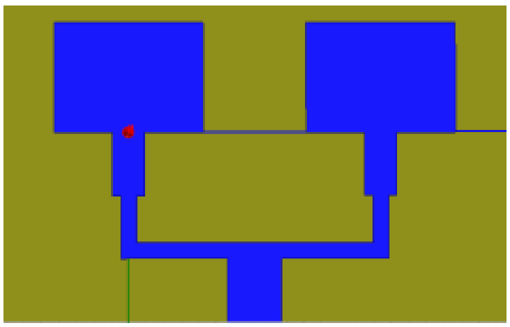
a. Patch with reflector b. Patch with Director c. Patch with reflector and director

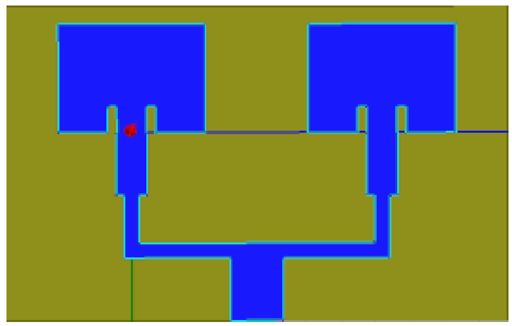
Figu re 3. 5 Single element microstrip patch array antenna for FR 4 with reflector and director

3.7 Design of Two-Element Microstrip Patch Antenna Array

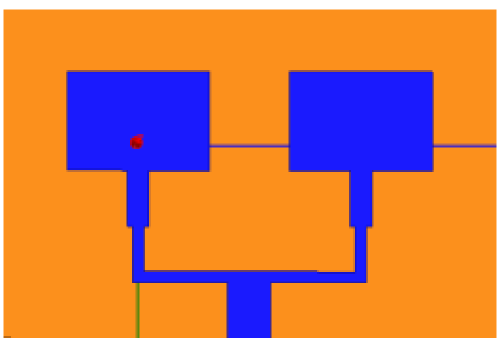
The array elements are fed using a corporate feeding mechanism. In this design, a two-way power divider is employed to split a 50 Ω feed line into a 100 Ω feed line. To match the edge impedance of the 100 Ω lines, 70 Ω quarter-wave transformers are used. The characteristic impedance of the quarter-wave transmission line (Z_t) is calculated using the formula provided in equation 3.18.

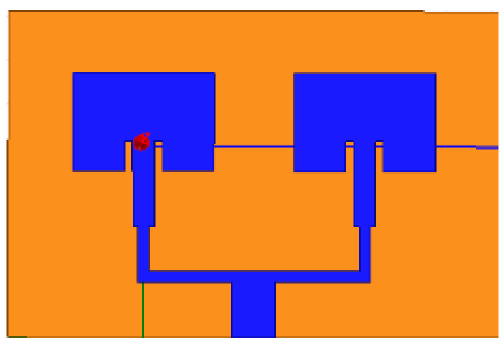
$$Z = \sqrt{50 * 100} \quad 70.7 \text{ ohm}$$



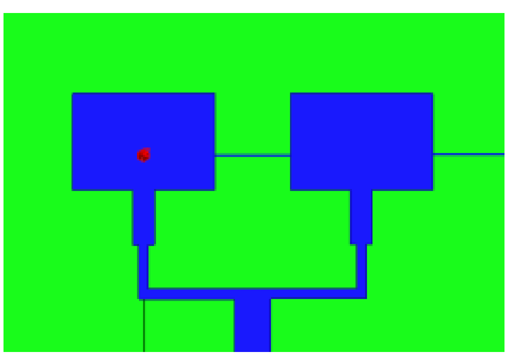


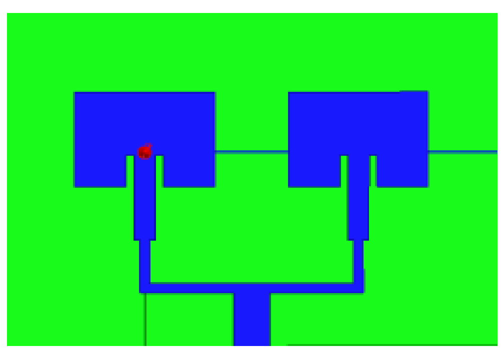
a. Two element patch of RT duroid without cut   b. Two element patch of RT duroid with cut





c. Two element patch of FR 4 without cut   d. Two-element patch of FR 4 with cut





e. Two-element patch of FR 4 without cut   d. Two-element patch of FR 4 with cut

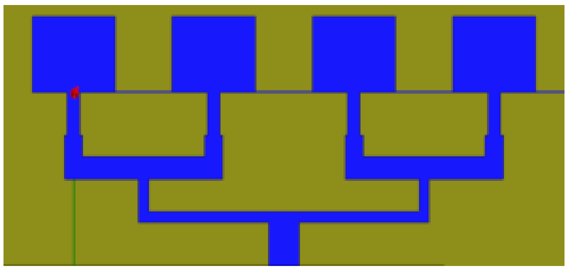
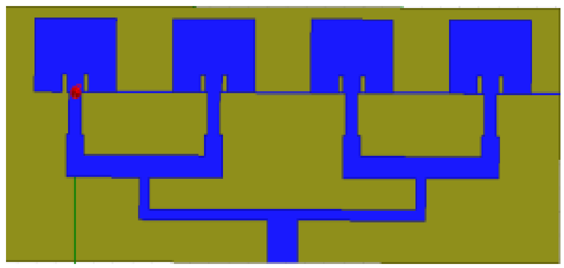
Figure 3. 6 Two-element microstrip patch array antenna

3.8 Design of Four-Element Microstrip Patch Antenna Array

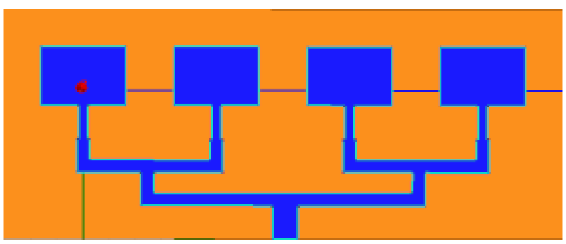
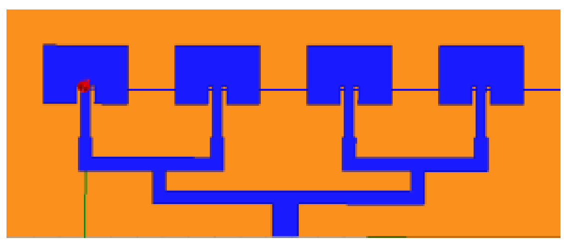
To feed the array elements, the corporate feeding technique is employed. In this setup, a two-way power divider splits a 50 Ω feed line into a 100 Ω feed line. Quarter-wave transformers with an impedance of 70.7 Ω are used to match the 100 Ω lines to the edge impedance. The last quarter wave transmission line characteristic impedance (Z) is given by equation;

$$Z = \sqrt{70.7 * 100} \quad 84 \text{ ohm}$$

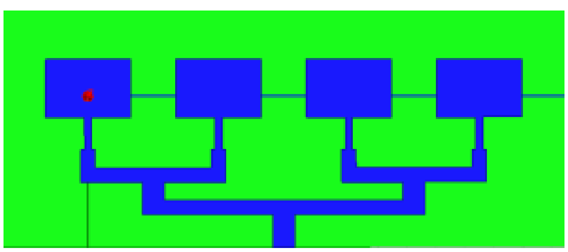
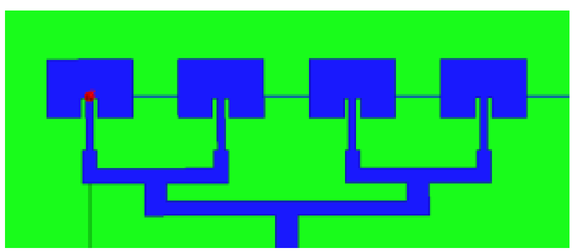
Where the separation between each patch is equal to the Wavelength λ.

a. Four element patch of RT duroid without cut   b. Four element patch of RT duroid with cut

c. Four element patch of FR 4 without cut   d. Four element patch of FR 4with cut

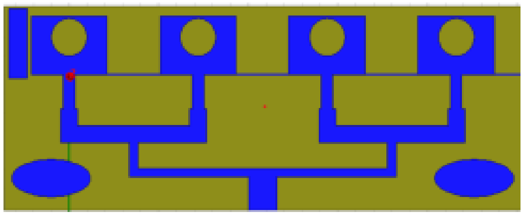
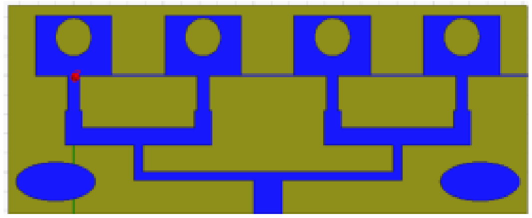



e. Four-element patch of mica without cut   f. Four-element patches of mica with cut

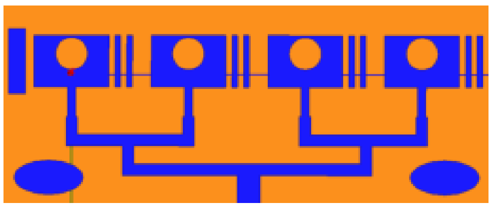
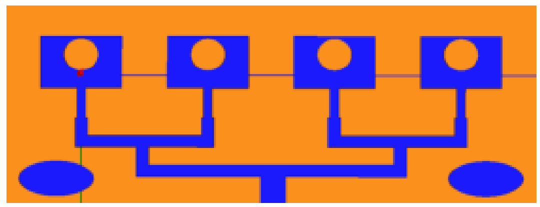
Figure 3. 7 Four-element microstrip patch array antenna

3.9 Design of Four-Element Microstrip Patch Antenna Array with Modification

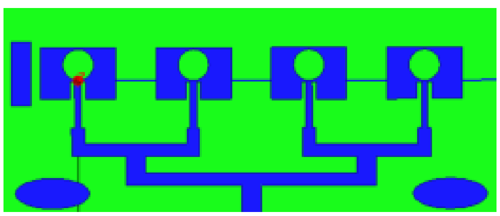
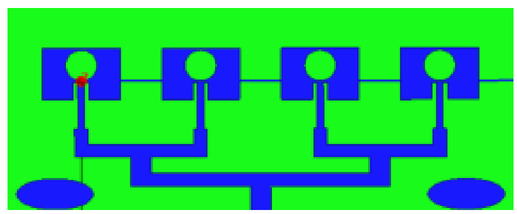
The corporate feeding method is chosen to feed the array elements. Two ellipses are added to the patch and four circles are removed from the patch.

a. Four-element patch of RT droid with Ref. b. Four-element patch of RT duroid with ellipse

c. Four-element patches of FR4 with Ref. d. Four-element patch of FR4 with ellipse

e. Four-element patches of Mica with Ref. f. Four-element patch of Mica with ellipse

Figure 3. 8 Four-element microstrip patch array antenna with modification

4. RESULTS AND DISCUSSIONS

4.1 Return Loss of a Single Element Microstrip Patch Antenna Array

4.1.1 Return loss of single element microstrip patch antenna with RT-duroid 5880

The return loss of an antenna should be below -10 dB to ensure efficient matching between the transmitter and the antenna. he measured return loss values for various configurations of a single-element microstrip patch antenna are given as follows; RT without cut at 28.5 GHZ is -10.22 dB, RT with cut at 29.3 GHz is -18.79 dB, RT with one reflector at 29.8 GHZ is -13.49 dB, RT with one director at 29.0 GHZ is -41.49 dB, RT with one reflector and one director at 28.8 GHZ is -13.53 dB, and RT with one reflector and two director at 29.3 GHZ and 31.0 GHz is -14. 04 dB and -24.12 dB respectively. The designed antenna of single element patch; RT with one director has a good return loss that is -41.49 dB at 29.0 GHz a resonant frequency.

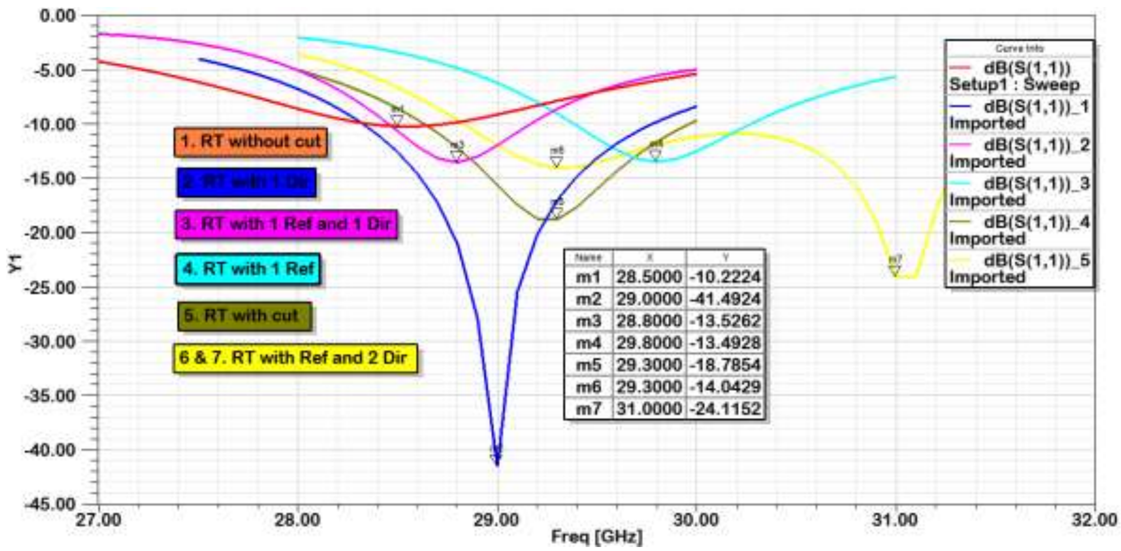


Figure 4. 5: Return loss of single element microstrip patch antenna for RT-duroid 5880

4.1.2 Return loss of single element microstrip patch antenna for FR 4

The return loss obtained from single element patch given as follows; FR 4 without cut at 28.7 GHZ is -11.67 dB, FR 4 with cut at 28.9 GHz is -19.25 dB, FR 4 with one reflector at 29.5 GHZ is -30.89 dB, FR 4 with one director at 28.6 GHZ is -14.87 dB, FR 4 with one reflector and one director at 29.1 GHZ is -16.21 dB, and FR 4 with two director at 29.9 GHZ is -16.32 dB respectively. The designed antenna of single element patch; FR 4 with one reflector has a good return loss that is -30.89 dB at 29.5 GHz a resonant frequency.

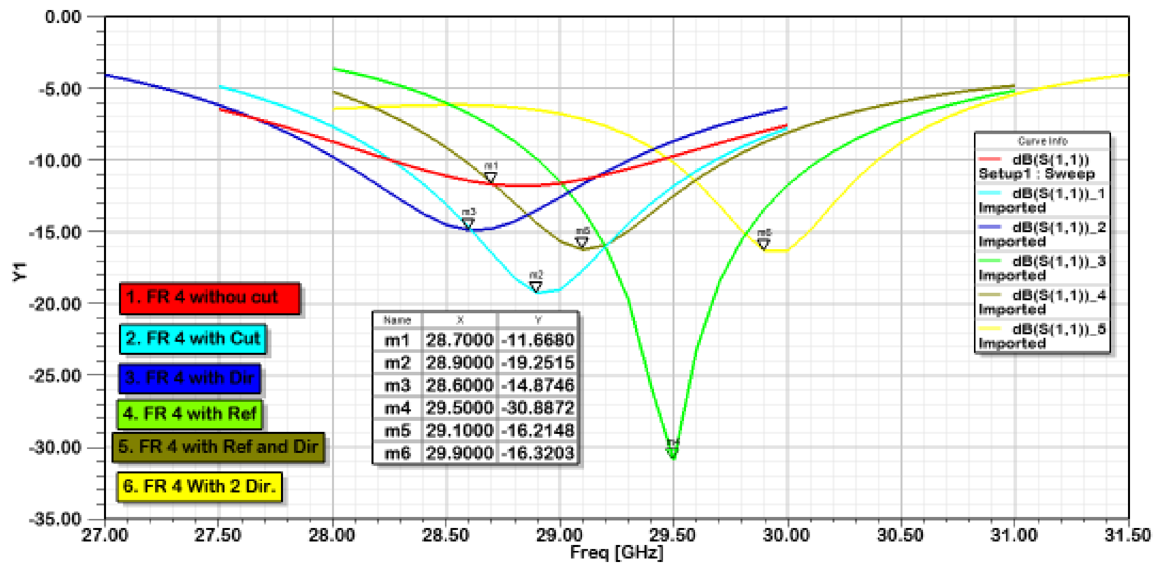


Figure 4. 6: Return loss of single element microstrip patch antenna for FR 4

4.1.3 Return loss of single element microstrip patch antenna for Mica

The return loss obtained from single element patch given as follows; Mica without cut at 28.0 GHZ is -7.27 dB, Mica with cut at 28.0GHz is -24.2 dB, Mica with one reflector at 28.7 GHZ is -21.16 dB, Mica with one director at 27.7 GHZ is -16.52 dB, Mica with one reflector and one director at 28.2 GHZ is -17.92 dB, and Mica with two director at 27.5 GHZ is -11.2 dB respectively. The designed antenna of single element patch; Mica with cut has a good return loss that is -24.2 dB at 28 GHz a resonant frequency.

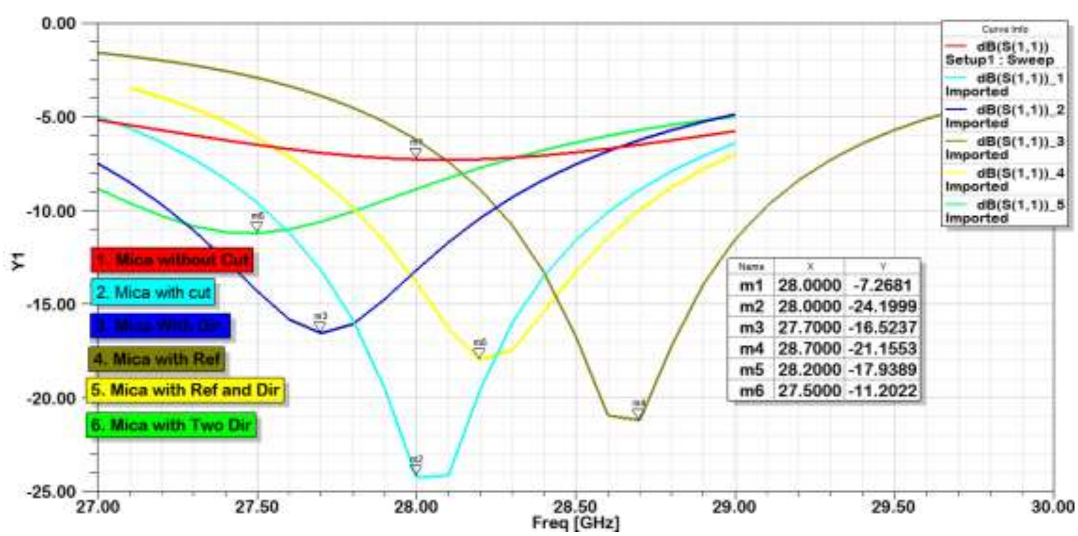


Figure 4. 7: Return loss of single element microstrip patch antenna for Mica

4.2 VSWR of Single Element Microstrip Patch Antenna Array

4.2.1 VSWR of single element microstrip patch antenna for RT-duroid 5880

The acceptable value of VSWR should be less than 2. The VSWR obtained from single element patch given as follows; RT without cut at 28.5 GHZ is 1.83, RT with cut at 29.3 GHz is 1.26, RT with one reflector at 29.8 GHZ is 1.53, RT with one director at 29.0 GHZ is 1.01, RT with one reflector and one director at 28.8 GHZ is 1.53, and RT with one reflector and two director at 29.2 GHZ is 1.51. The designed antenna of single element patch; RT with one director has a good VSWR that is 1.01 at 29.0 GHz a resonant frequency.

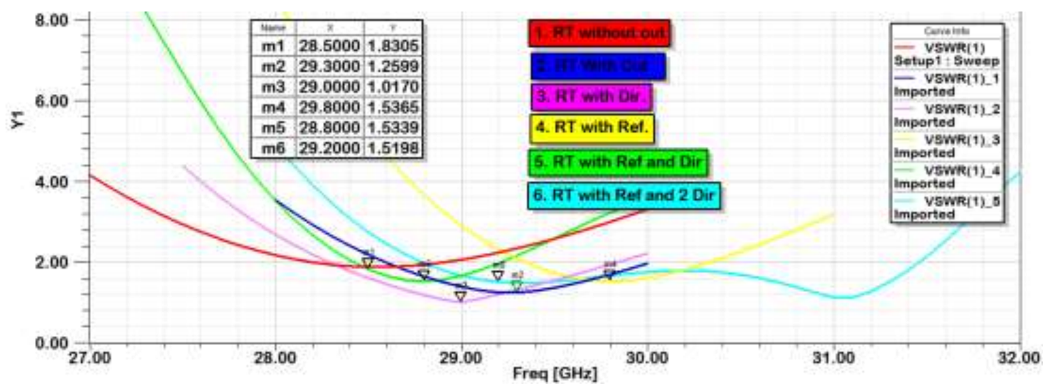


Figure 4. 8: VSWR of single element microstrip patch antenna for RT-duroid 5880

4.2.2 VSWR of single element microstrip patch antenna for FR 4

The VSWR obtained from single element patch given as follows; FR 4 without cut at 28.7 GHZ is 1.70, FR 4 with cut at 28.9GHz is 1.24, FR 4 with one reflector at 29.5 GHZ is 1.05, FR 4 with one director at 28.6 GHZ is 1.44, FR 4 with one reflector and one director at 29.1 GHZ is 1.36, and FR 4 with one reflector and two director at 29.2 GHZ is 1.51.

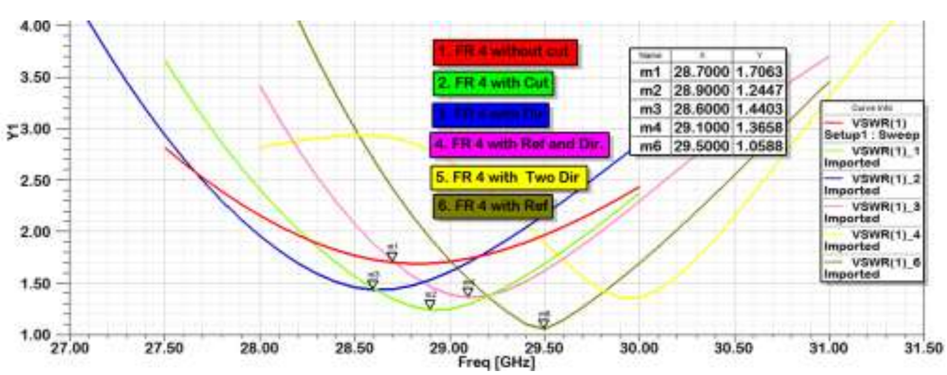


Figure 4. 9: VSWR of single element microstrip patch antenna for FR 4

The designed antenna of single element patch; FR 4 with one reflector has a good VSWR that is 1.06 at 29.5 GHz a resonant frequency.

4.2.3 VSWR of single element microstrip patch antenna for Mica

The VSWR obtained from single element patch given as follows; Mica without cut at 28.0 GHZ is 2.52, Mica with cut at 28.0 GHz is 1.13, Mica with one reflector at 28.7 GHZ is 1.19, Mica with one director at 27.7 GHZ is 1.35, Mica with one reflector and one director at 28.2 GHZ is 1.29, and Mica with one reflector and two director at 27.5 GHZ is 1.76. The designed antenna of single element patch; Mica with cut has a good VSWR that is 1.13 at 28 GHz a resonant frequency.

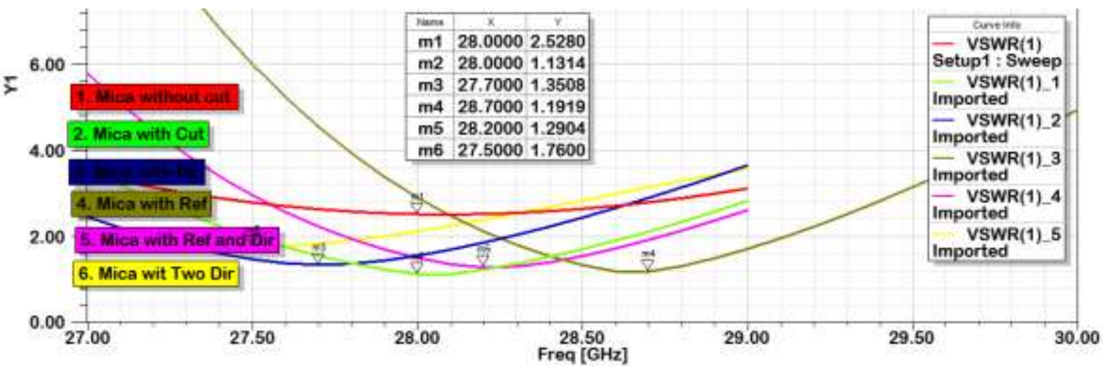
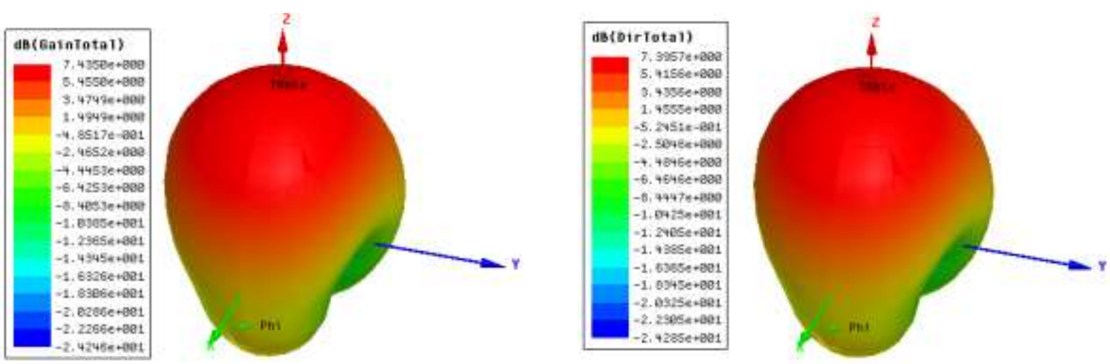


Figure 4. 10: VSWR of single element microstrip patch antenna for Mica

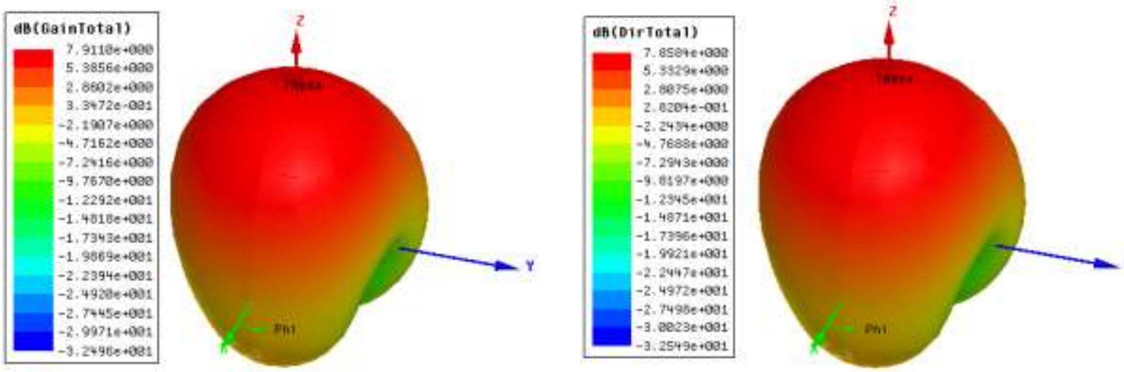
4.3 Gain and Directivity of a Single Element Microstrip Patch Antenna Array

4.3.1 Gain and directivity of a single element microstrip patch antenna using RT-duroid 5880

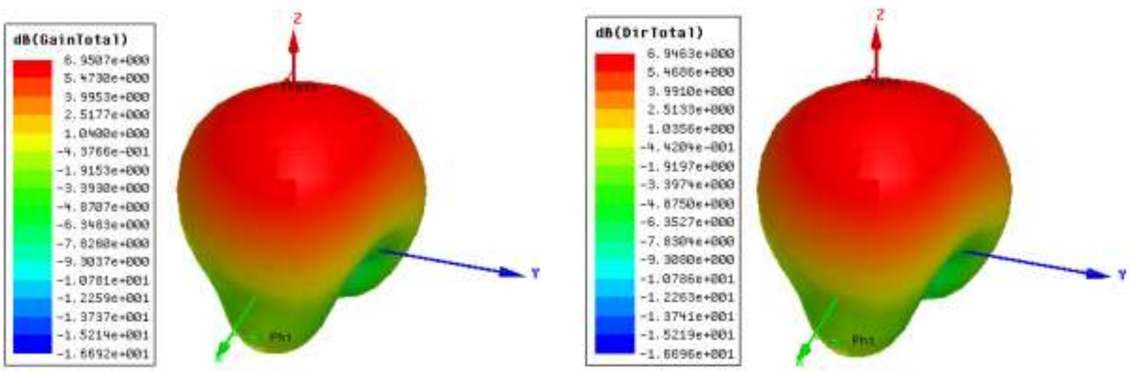
The single-element microstrip patch antenna with one director achieves a gain of 8.1 dB and a directivity of 8.07 dB at an operating frequency of 29.0 GHz.



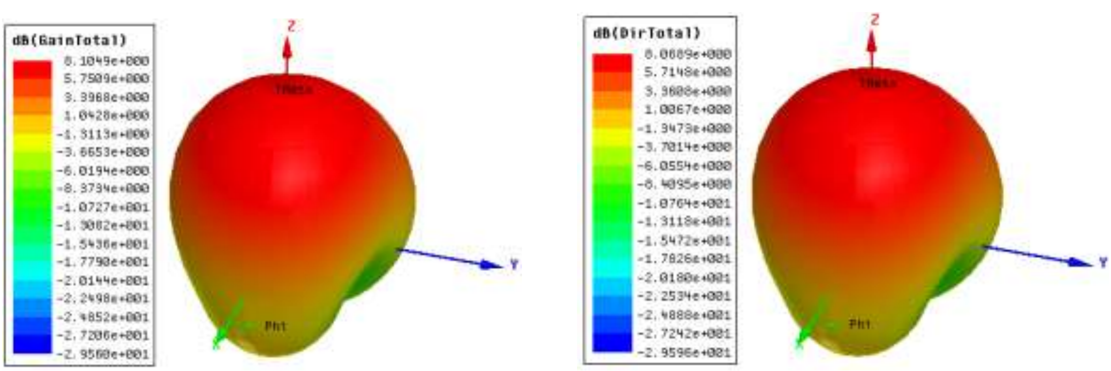
a. Gain and directivity of single element patch without cut



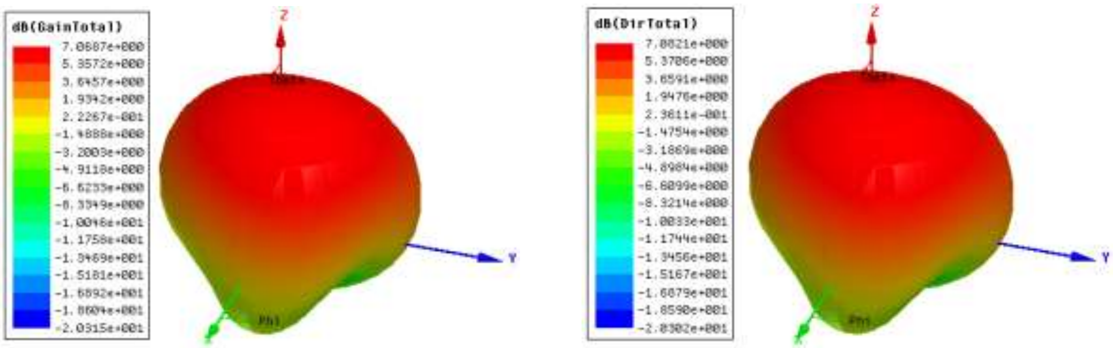
b. Gain and directivity of single element patch with cut



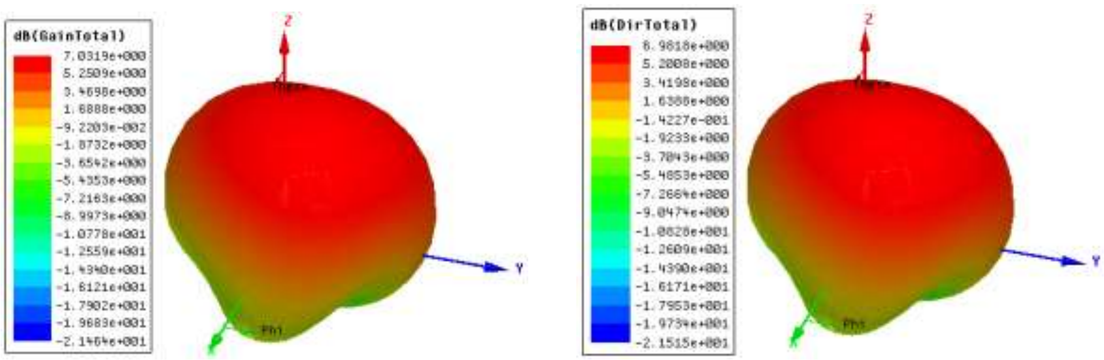
c. Gain and directivity of single element patch with one reflector



d. Gain and directivity of single element patch with one director



e. Gain and directivity of single element patch with one reflector and one director

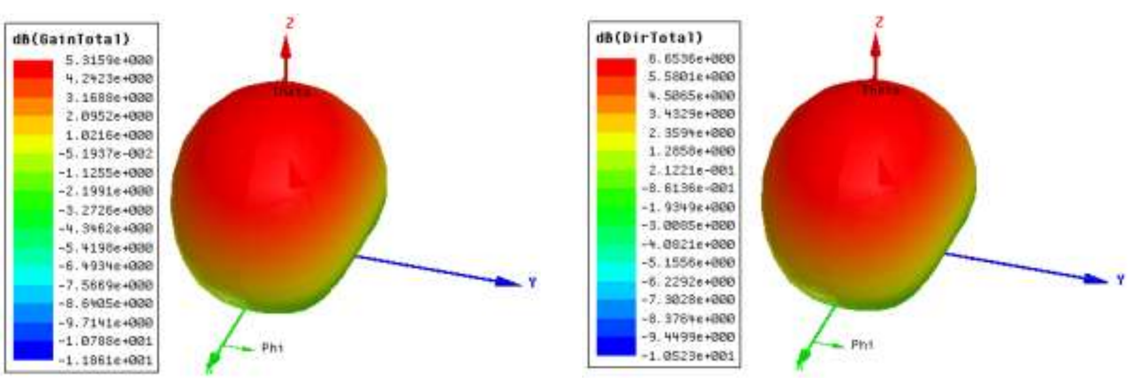


f. Gain and directivity of single element patch of with reflector and two director

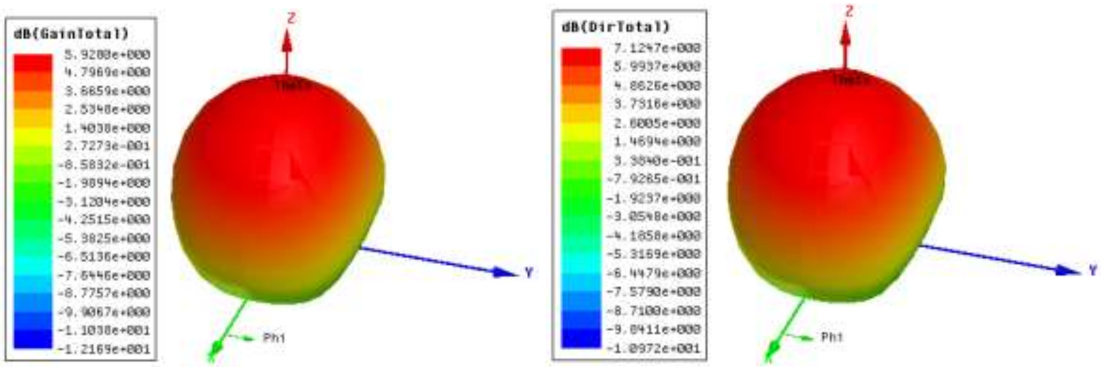
Figure 4. 11: Gain and directivity of single element microstrip patch antenna for RT-duroid 5880

4.3.2 Gain and directivity of single element microstrip patch antenna for RF 4

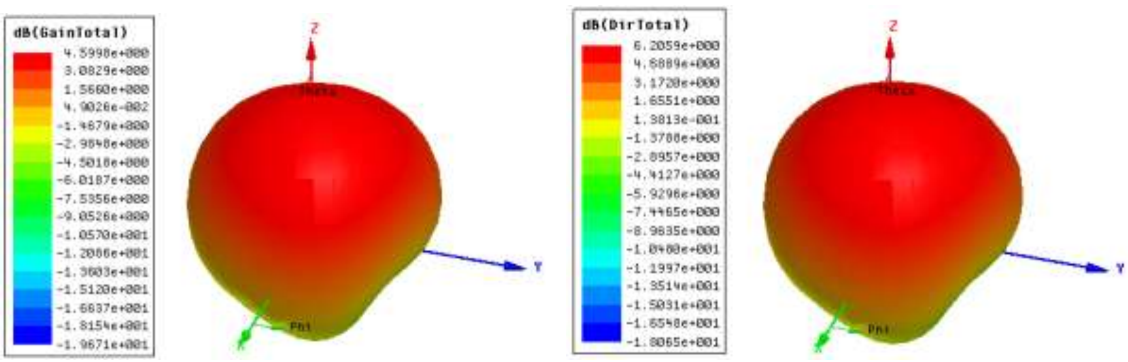
The single-element patch with one director achieves a higher gain of 6.03 dB and a directivity of 7.15 dB at an operating frequency of 28.6 GHz.



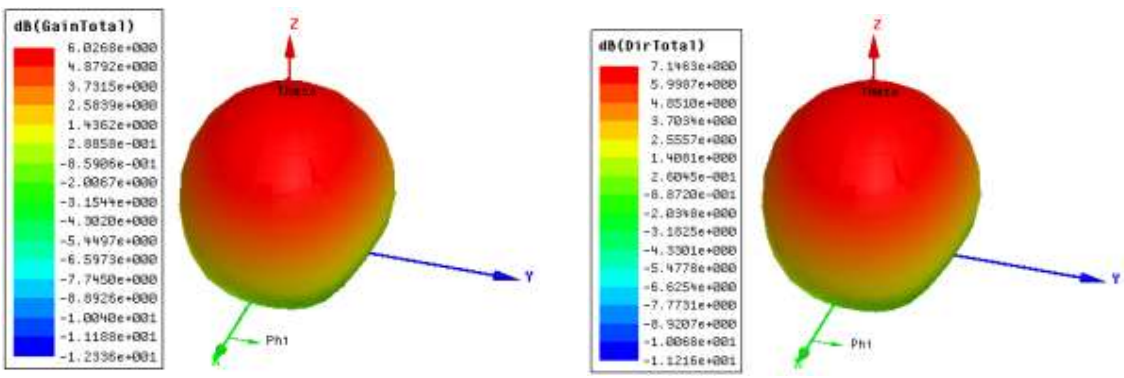
a. Gain and directivity of single element patch without cut



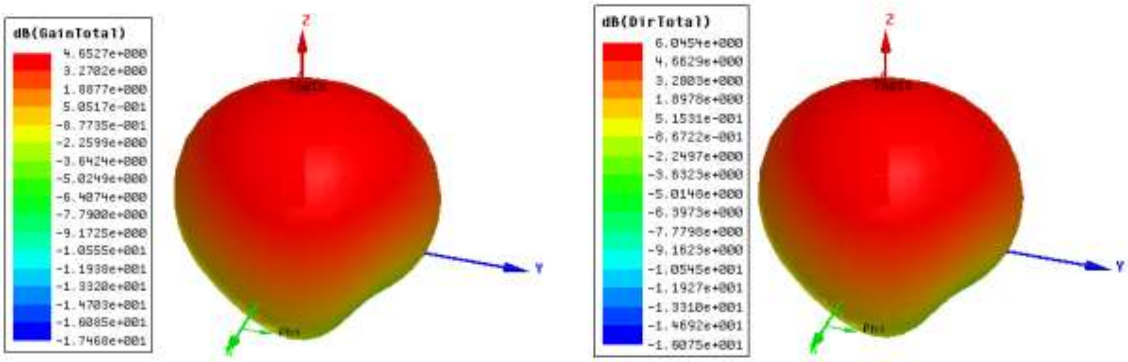
b. Gain and directivity of single element patch with cut



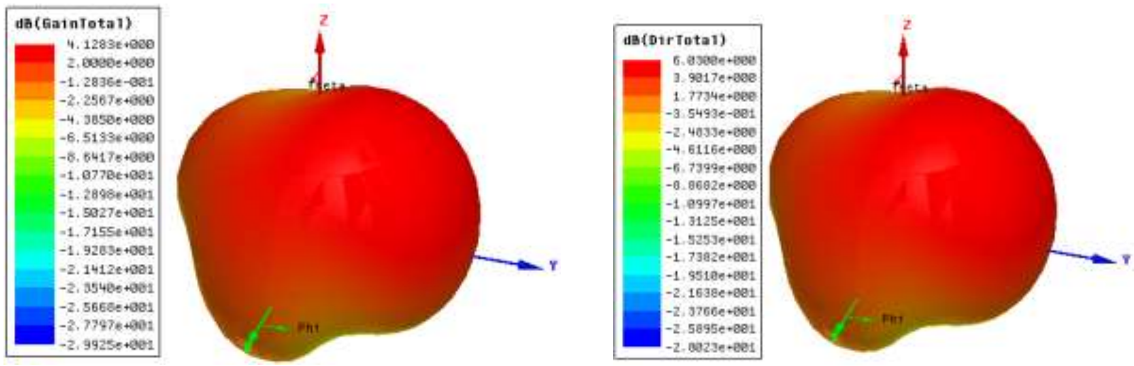
c. Gain and directivity of single element patch with one reflector



d. Gain and directivity of single element patch with one director



e. Gain and directivity of single element patch with one reflector and one director

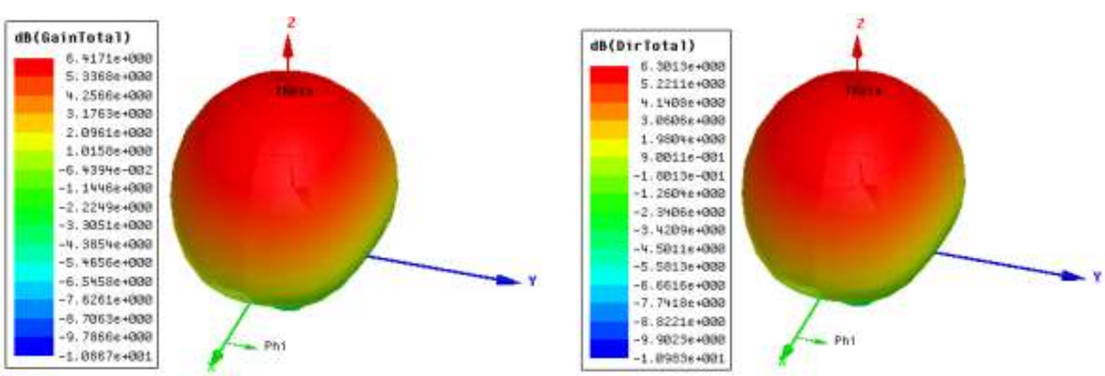


f. Gain and directivity of single element patch of with two director

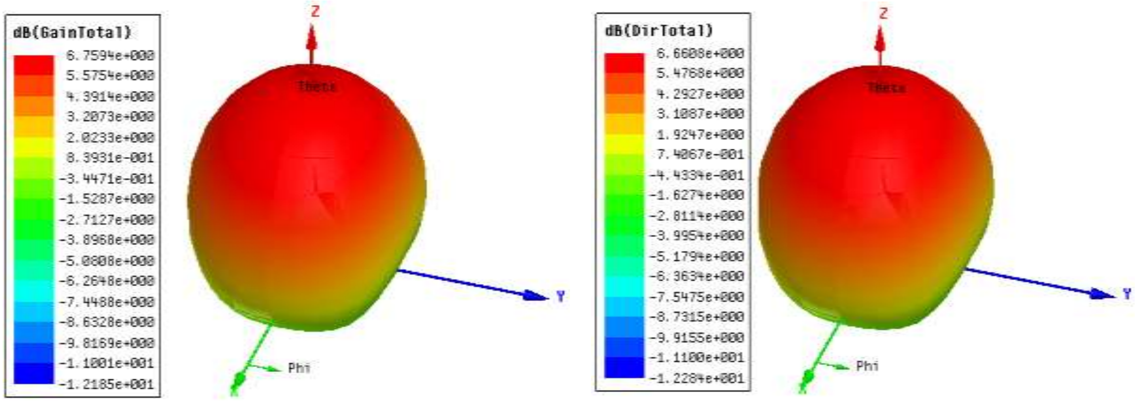
Figure 4. 12: Gain and directivity of single element microstrip patch antenna for FR4

4.3.3 Gain and directivity of single element microstrip patch antenna for Mica

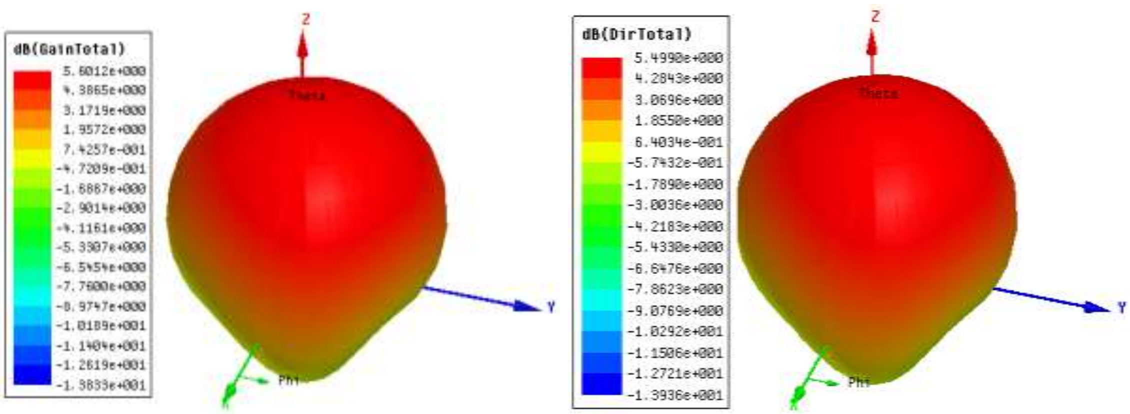
The higher gain and directivity obtained from the single element patch with cut, which is 6.76 dB and 6.66 dB at 28 GHz operating frequency respectively.



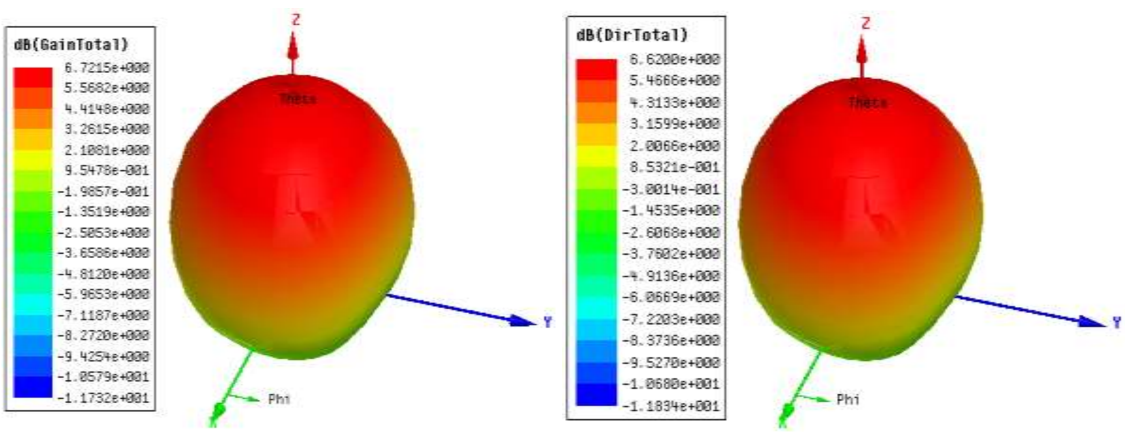
a. Gain and directivity of single element patch without cut



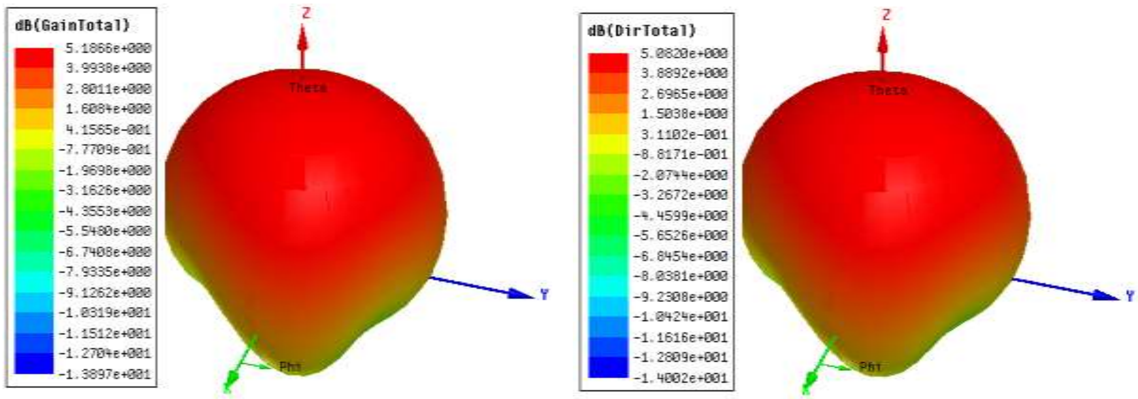
b. Gain and directivity of single element patch with cut



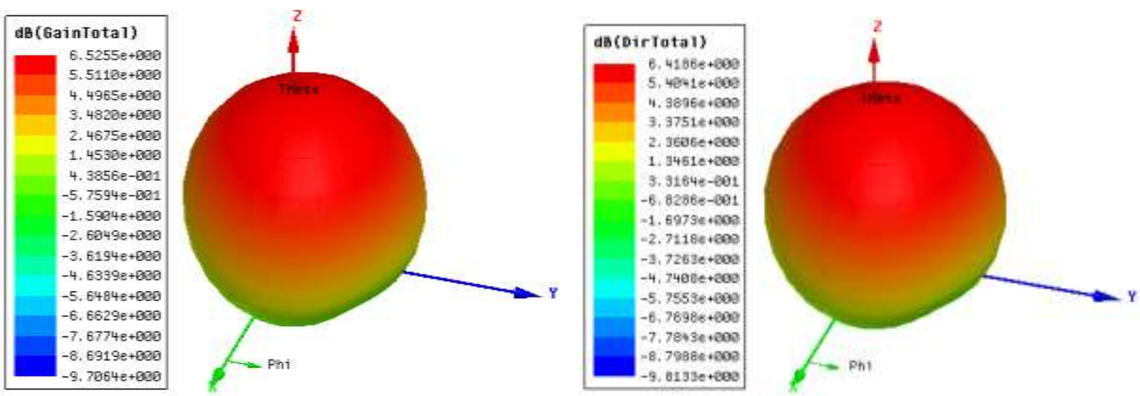
c. Gain and directivity of single element patch with one reflector



d. Gain and directivity of single element patch with one director



e. Gain and directivity of single element patch with one reflector and one director

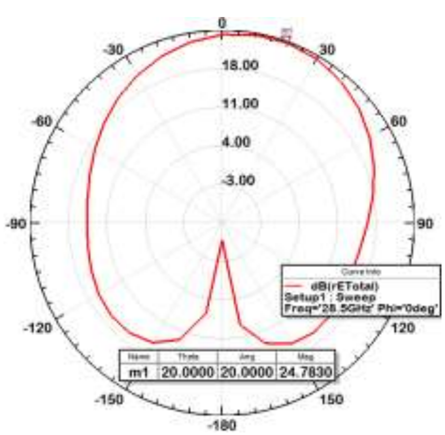


f. Gain and directivity of single element patch of with reflector and two director

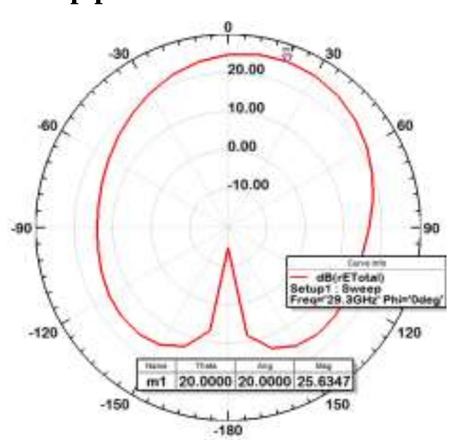
Figure 4.13: Gain and directivity of single element microstrip patch antenna for FR4

4.4 Radiation Pattern of Single Element Microstrip Patch Antenna Array

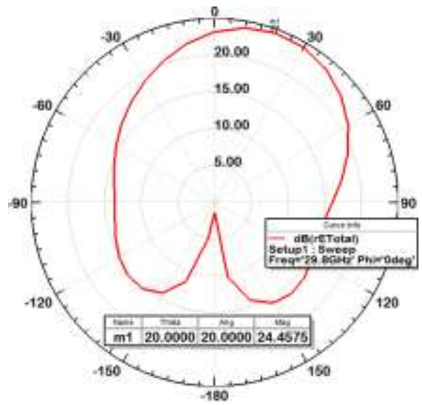
4.4.1 Radiation pattern of single element microstrip patch antenna for RT-duroid 5880



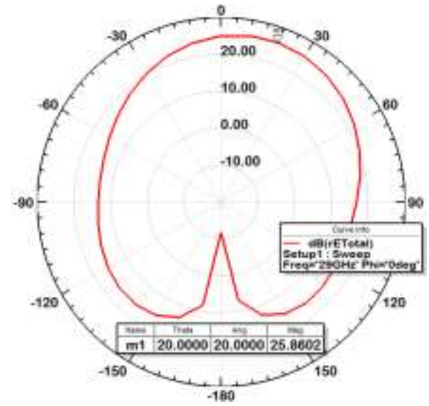
a. Radiation pattern without cut



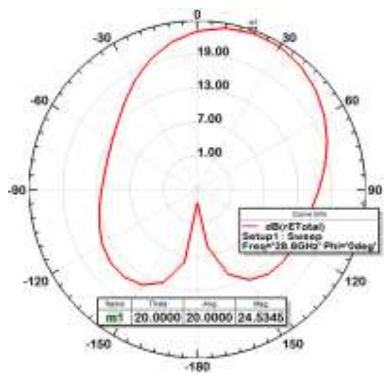
b. radiation pattern with cut



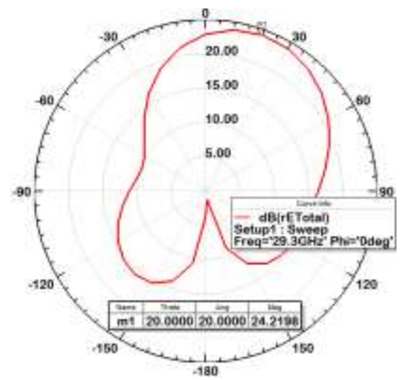
c. Radiation Pattern with One Reflector



d. Radiation Pattern with One Director



e. Radiation Pattern with one Ref. and One Dir.

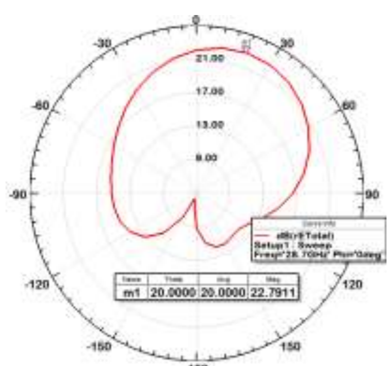


f. Radiation Pattern with Ref. and two Dir.

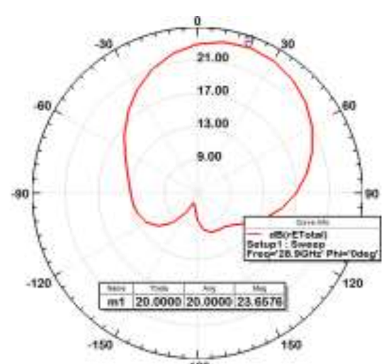
Figure 4. 14: Radiation pattern of single element microstrip patch antenna for RT-duroid 5880

The main lobe direction radiation pattern of single element patch with one director is 20^0 with 25.86 dB magnitude at 29.0 GHz operating frequency.

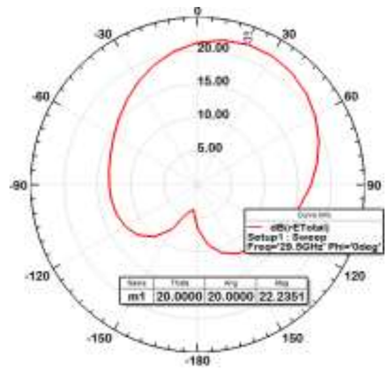
4.4.2 Radiation pattern of single element microstrip patch antenna for FR 4



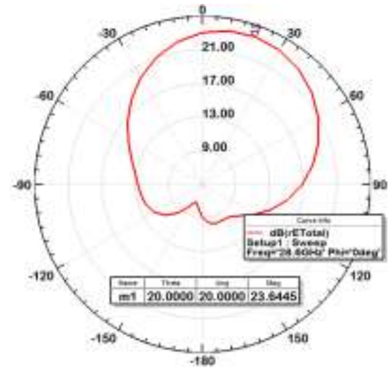
a. Radiation pattern without cut



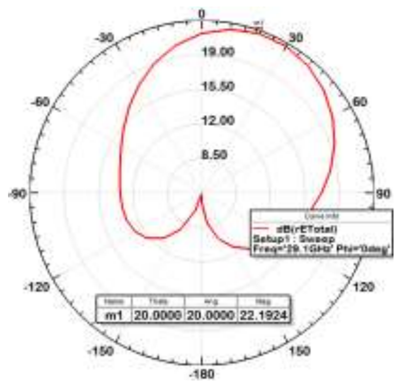
b. Radiation pattern with cut



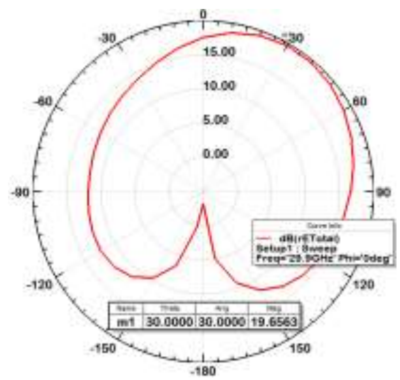
c. Radiation Pattern with One Reflector



d. Radiation Pattern with One Director



e. Radiation Pattern with one Ref. and One Dir.

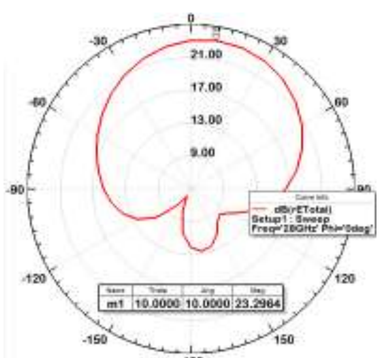


f. Radiation Pattern with two Director

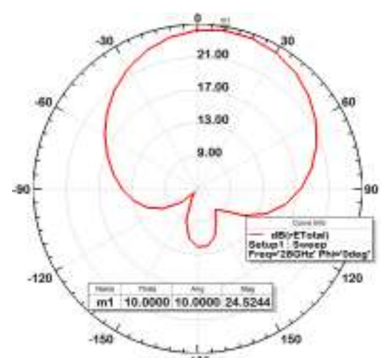
Figure 4. 15: Radiation pattern of single element microstrip patch antenna for FR 4

The main lobe direction radiation pattern of single element patch with cut is 20^0 with 23.66 dB magnitude at 28.9 GHz operating frequency.

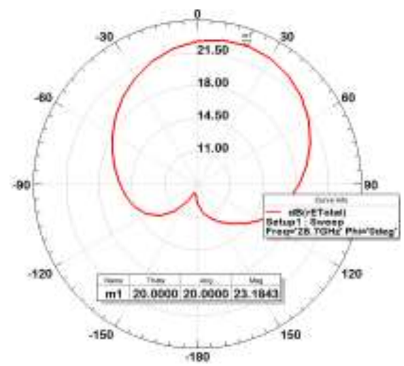
4.4.3 Radiation pattern of single element microstrip patch antenna for Mica



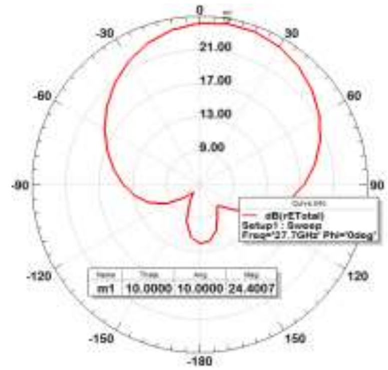
a. Radiation pattern without cut



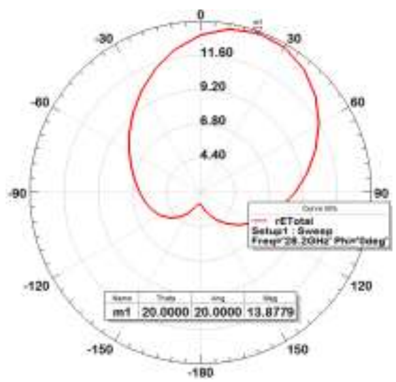
b. radiation pattern with cut



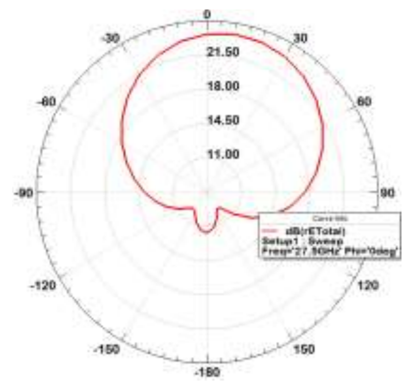
c. Radiation Pattern with One Reflector



d. Radiation Pattern with One Director



e. Radiation Pattern with one Ref. and One Dir.



f. Radiation Pattern with two Director

Figure 4.16: Radiation pattern of single element microstrip patch antenna for FR 4

The main lobe direction radiation pattern of single element patch with cut is 20^0 with 24.52 dB magnitude at 28.0 GHz operating frequency.

4.5 Return Loss of Two Element Microstrip Patch Antenna Array

4.5.1 Return loss of two element microstrip patch antenna for RT-duroid 5880

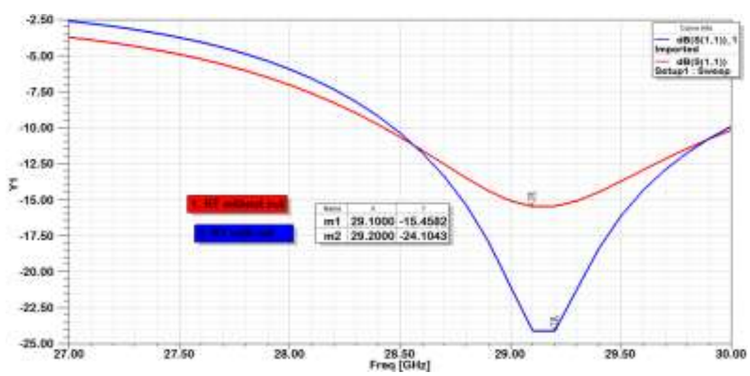


Figure 4. 17: Return loss of two element microstrip patch antenna for RT-duroid 5880

The designed antenna of two element patch; RT-duroid 5880 with cut has a good return loss that is -24.10 dB at 29.2 GHz a resonant frequency.

4.5.2 Return loss of two element microstrip patch antenna for FR 4

The designed antenna of two element patch; FR 4 without cut has a good return loss that is -26.03 dB at 28.7 GHz a resonant frequency.

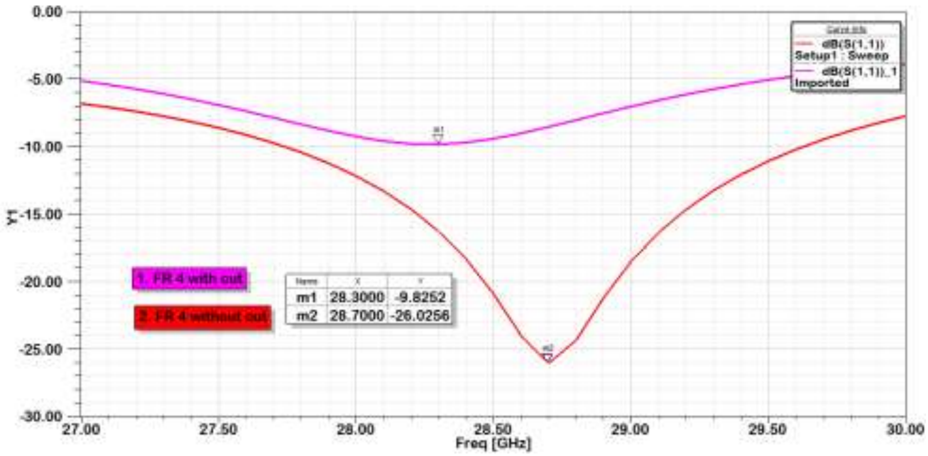


Figure 4. 18: Return loss of two element microstrip patch antenna for FR 4

4.5.3 Return loss of two element microstrip patch antenna for Mica

The designed antenna of two element patch; Mica with cut has a good return loss that is -12.32 dB at 27.5 GHz a resonant frequency.

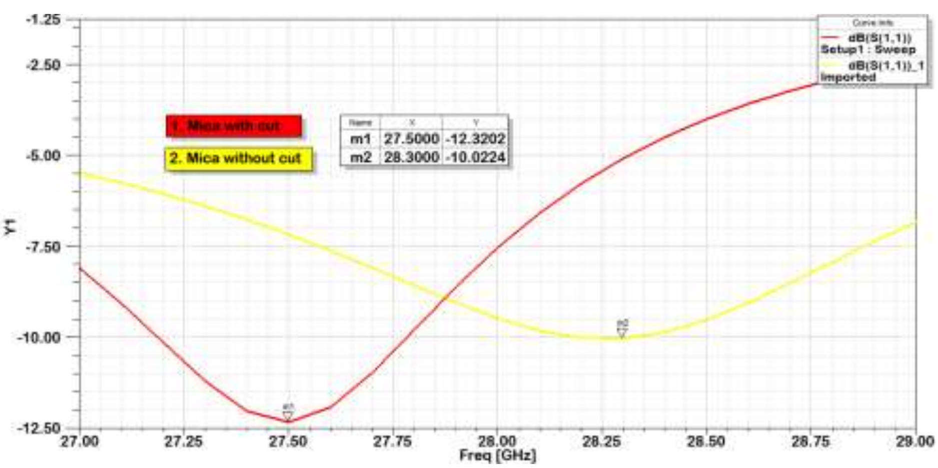


Figure 4. 19: Return loss of two element microstrip patch antenna for Mica

4.6 VSWR of Two Element Microstrip Patch Antenna Array

4.6.1 VSWR of two element microstrip patch antenna for FR 4

The designed antenna of two element patch; RT with cut has a good VSWR that is 1.13 at 29.2 GHz a resonant frequency.

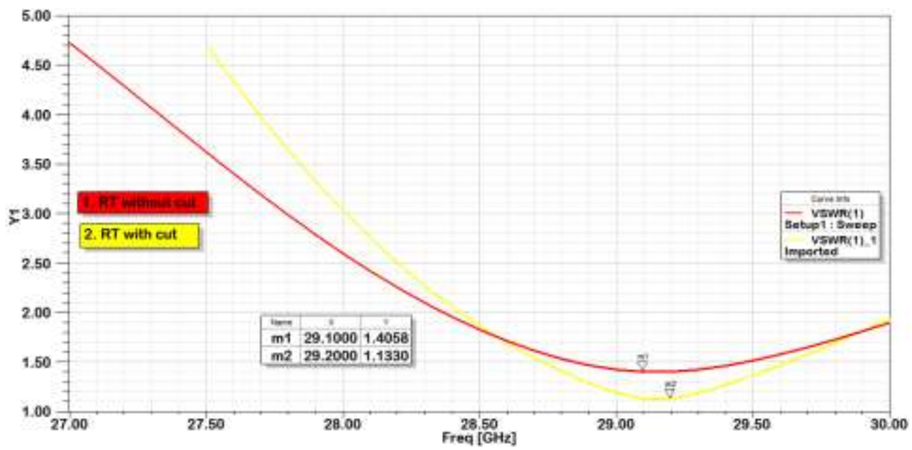


Figure 4. 20: VSWR of two element microstrip patch antenna for RT-duroid 5880

4.6.2 VSWR of two element microstrip patch antenna for FR 4

The designed antenna of two element patch; FR 4 without cut has a good VSWR that is 1.10 at 28.7 GHz a resonant frequency.

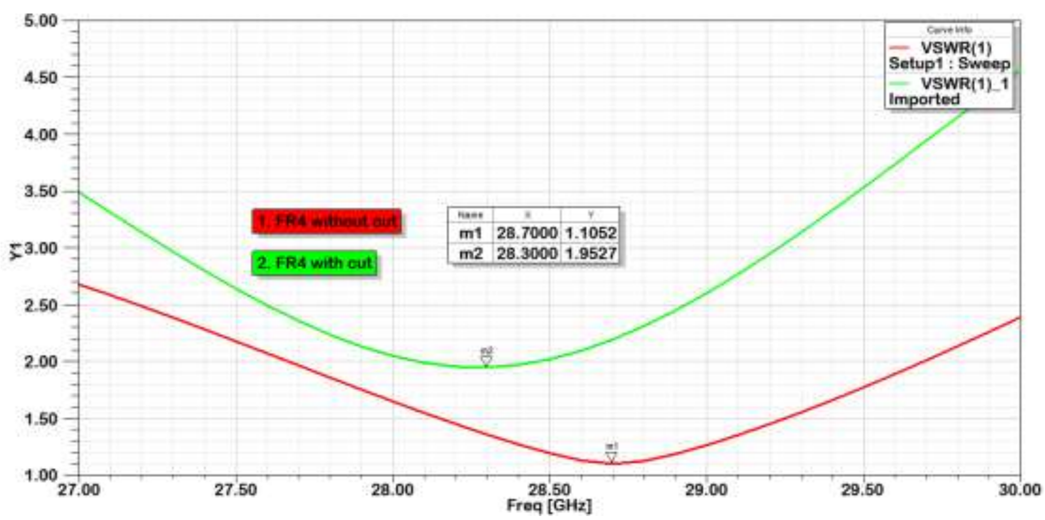


Figure 4. 21: VSWR of two element microstrip patch antenna for FR 4

4.6.3 VSWR of two element microstrip patch antenna for Mica

The designed antenna of two element patch; Mica with cut has a good VSWR that is 1.63 at 27.5 GHz a resonant frequency.

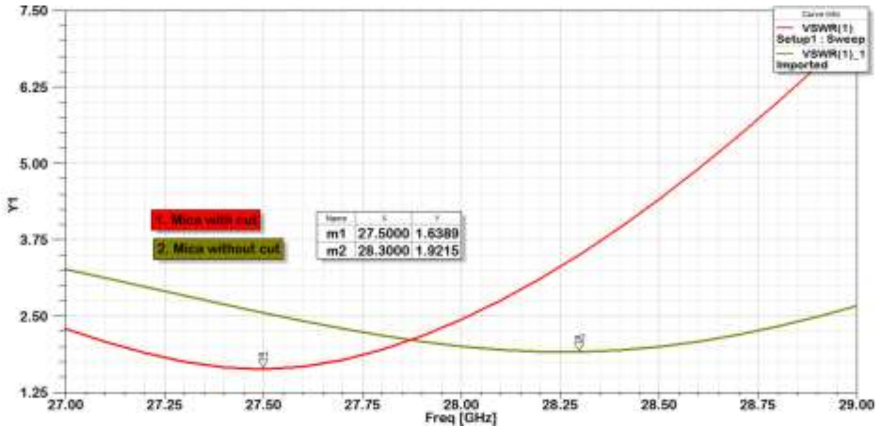
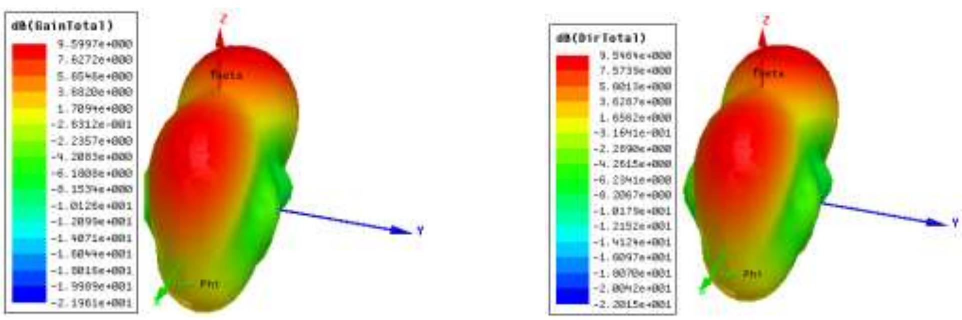


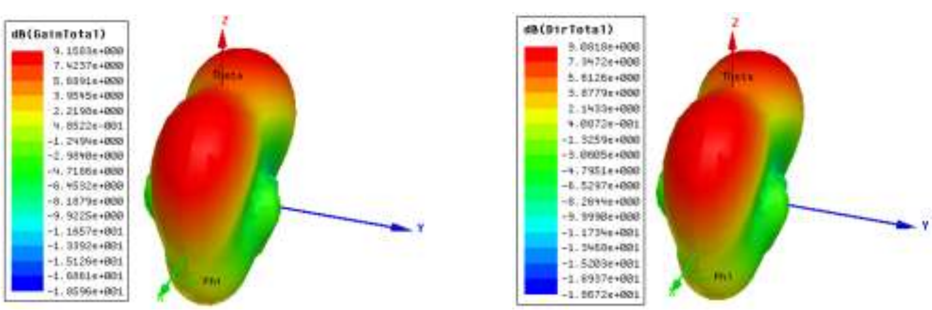
Figure 4. 22: VSWR of two element microstrip patch antenna for Mica

4.7 Gain and Directivity of Two Element Microstrip Patch Antenna Array

4.7.1 Gain and directivity of two element microstrip patch antenna for RT-duroid 5880



a. Gain and directivity of two element patch without cut



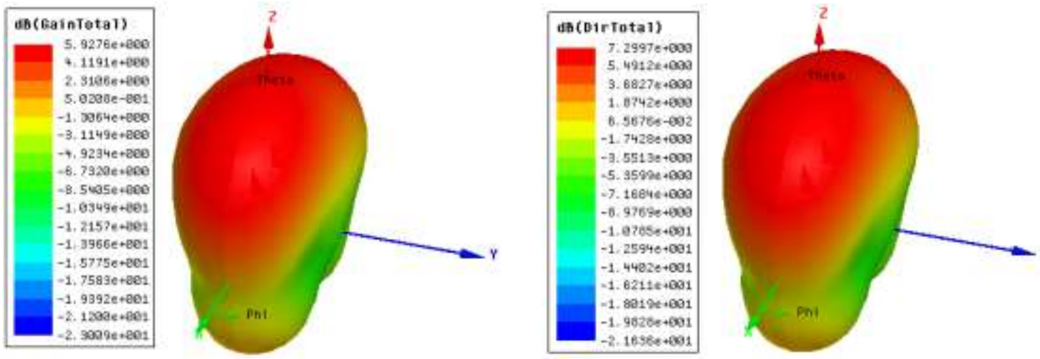
b. Gain and directivity of two element patch with cut

Figure 4. 23: Gain and directivity of two element microstrip patch antenna for RT-duroid 5880

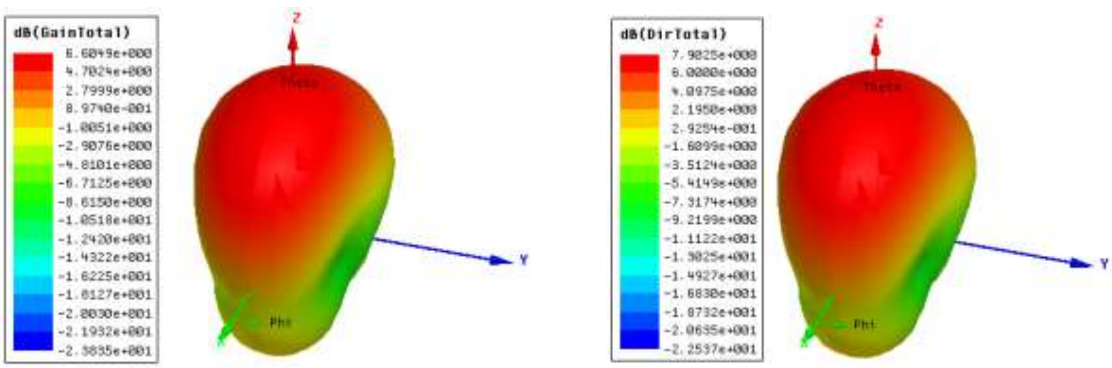
The higher gain and directivity obtained from the two element patch with one director, which is 8.1 dB and 8.07 dB at 29.0 GHz operating frequency respectively.

4.7.2 Gain and directivity of two element microstrip patch antenna for RF 4

The higher gain and directivity obtained from the two element patch with one director, which is 6.03 dB and 7.15 dB at 28.6 GHz operating frequency respectively.



c. Gain and directivity of two element patch without cut

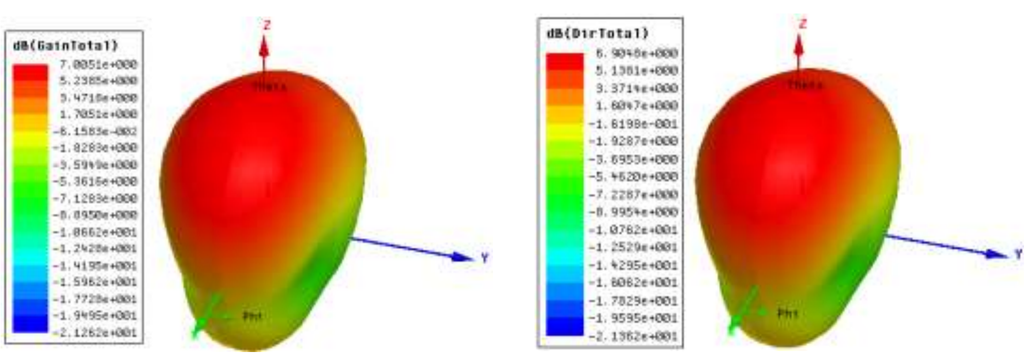


d. Gain and directivity of two element patch with cut

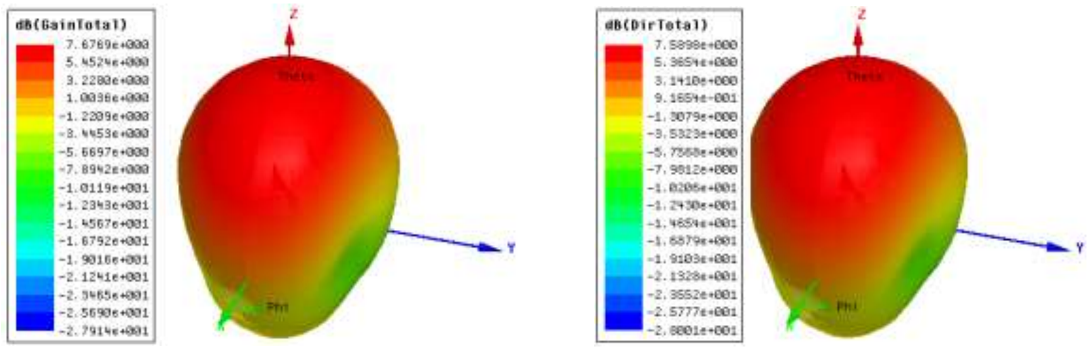
Figure 4. 24: Gain and directivity of two element microstrip patch antenna for FR4

4.7.3 Gain and directivity of two element microstrip patch antenna for Mica

The higher gain and directivity obtained from the two element patch with cut, which is 6.76 dB and 6.66 dB at 28 GHz operating frequency respectively.



e. Gain and directivity of two element patch without cut

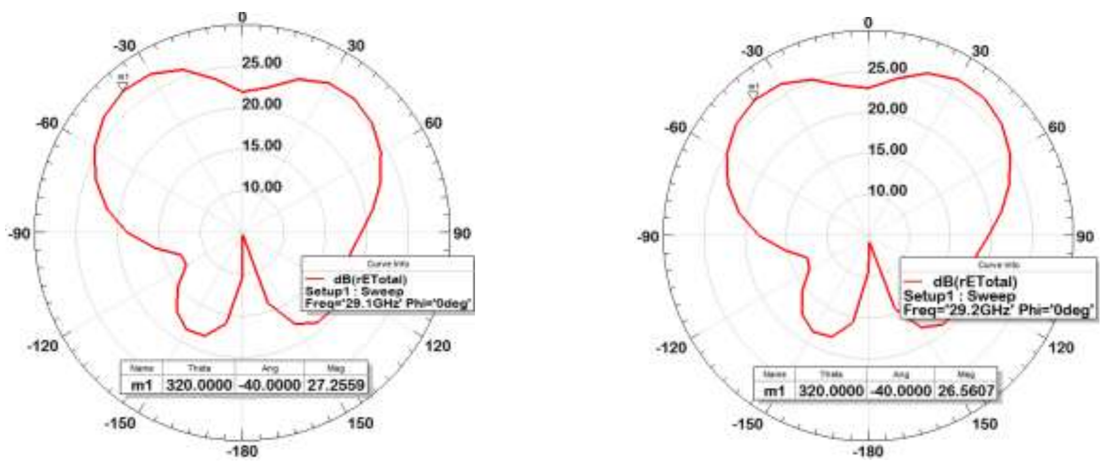


f. Gain and directivity of two element patch with cut

Figure 4. 25: Gain and directivity of two element microstrip patch antenna for FR4

4.8 Radiation Pattern of Two Element Microstrip Patch Antenna Array

4.8.1 Radiation pattern of two element microstrip patch antenna for RT-duroid 5880



a. Radiation pattern without cut

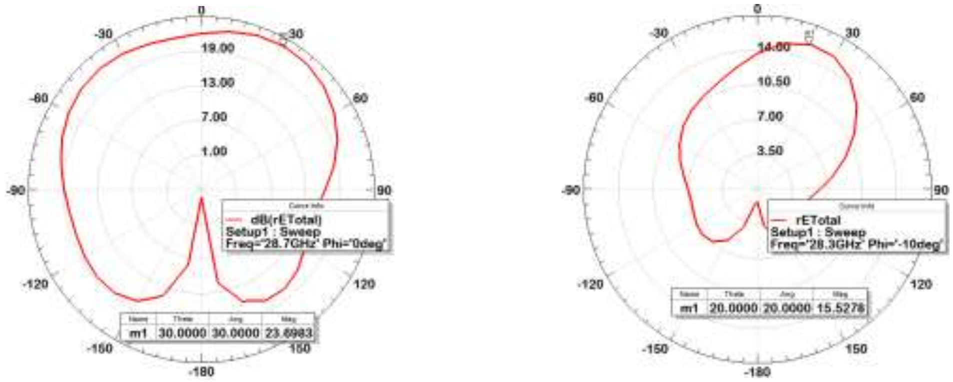
b. radiation pattern with cut

Figure 4. 26: Radiation pattern of two element microstrip patch antenna for RT-duroid 5880

The main lobe direction radiation pattern of two element patch without cut is -40^0 with 27.26 dB magnitude at 29.1 GHz operating frequency.

4.8.2 Radiation pattern of two element microstrip patch antenna for FR 4

The main lobe direction radiation pattern of two element patch with cut is 20^0 with 23.69 dB magnitude at 28.3 GHz operating frequency.

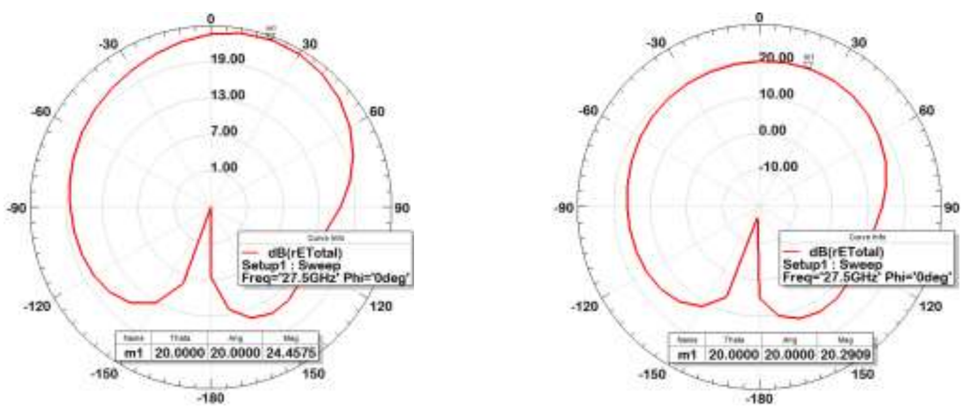


a. Radiation pattern without cut b. Radiation pattern with cut

Figure 4. 27: Radiation pattern of two element microstrip patch antenna for FR 4

4.8.3 Radiation pattern of two element microstrip patch antenna for Mica

The main lobe direction radiation pattern of two element patch without cut is 20^0 with 24.46 dB magnitude at 28.3 GHz operating frequency.



a. Radiation pattern without cut b. radiation pattern with cut

Figure 4. 28: Radiation pattern of two element microstrip patch antenna for FR 4

4.9 Return Loss of Four Element Microstrip Patch Antenna Array

4.9.1 Return loss of four element microstrip patch antenna for RT-duroid 5880

The designed antenna of four element patch; RT-duroid 5880 without cut has a good return loss that is -14.48 dB at 29.1 GHz a resonant frequency.

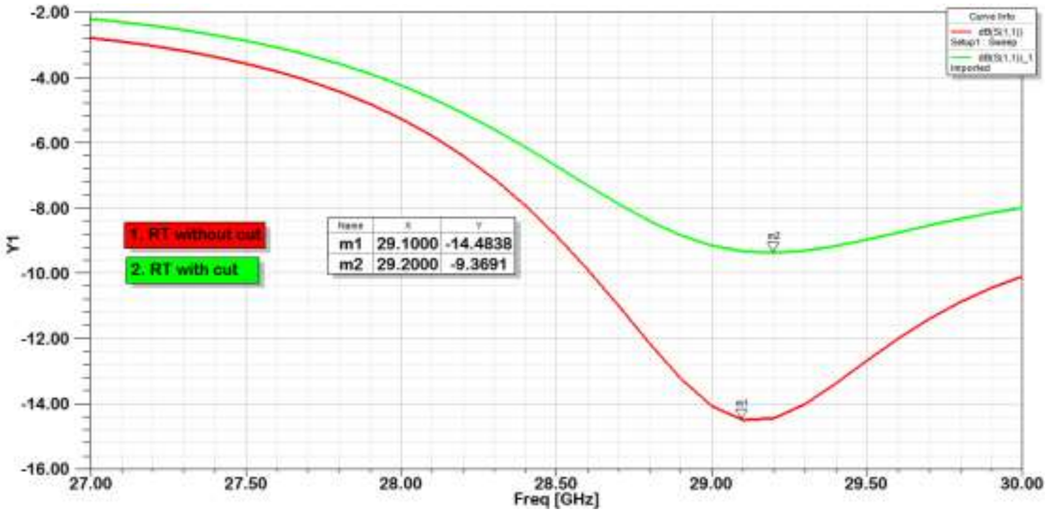


Figure 4. 29: Return loss of four element microstrip patch antenna for RT-duroid 5880

4.9.2 Return loss of four element microstrip patch antenna for FR 4

The designed antenna of four element patch; FR 4 without cut has a good return loss that is -11.19 dB at 28.2 GHz a resonant frequency.

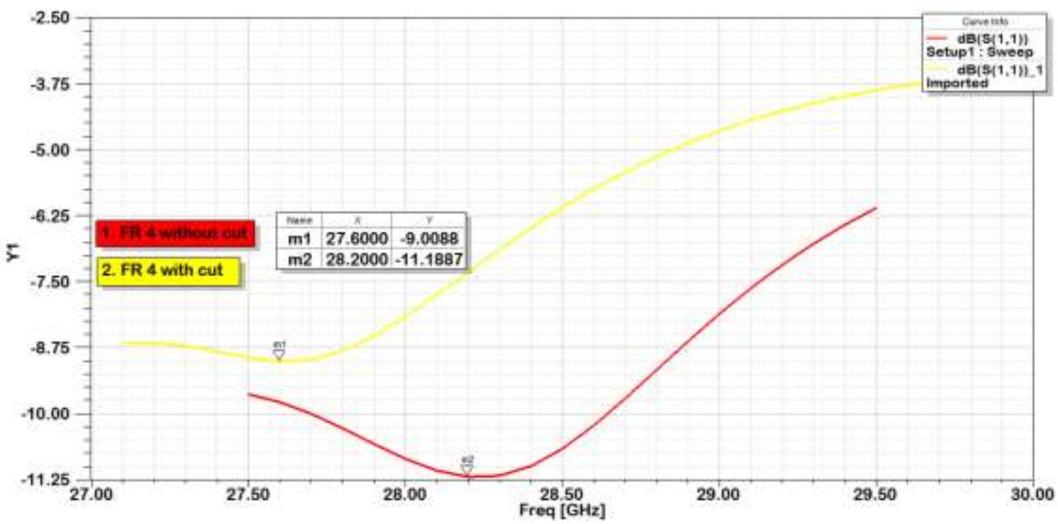


Figure 4. 30: Return loss of four element microstrip patch antenna for FR 4

4.9.3 Return loss of four element microstrip patch antenna for Mica

The designed antenna of four element patch; Mica without cut has a good return loss that is -24.84 dB at 27.4 GHz a resonant frequency.

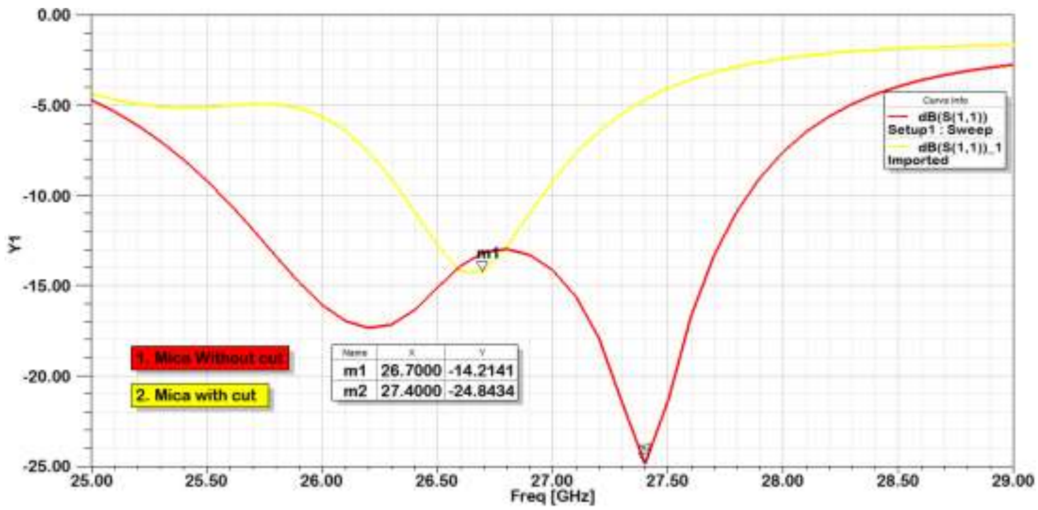


Figure 4. 31: Return loss of four element microstrip patch antenna for Mica

4.10 VSWR of Four Element Microstrip Patch Antenna Array

4.10.1 VSWR of four element microstrip patch antenna for FR 4

The designed antenna of four element patch; RT without cut has a good VSWR that is 1.46 at 29.1 GHz a resonant frequency.

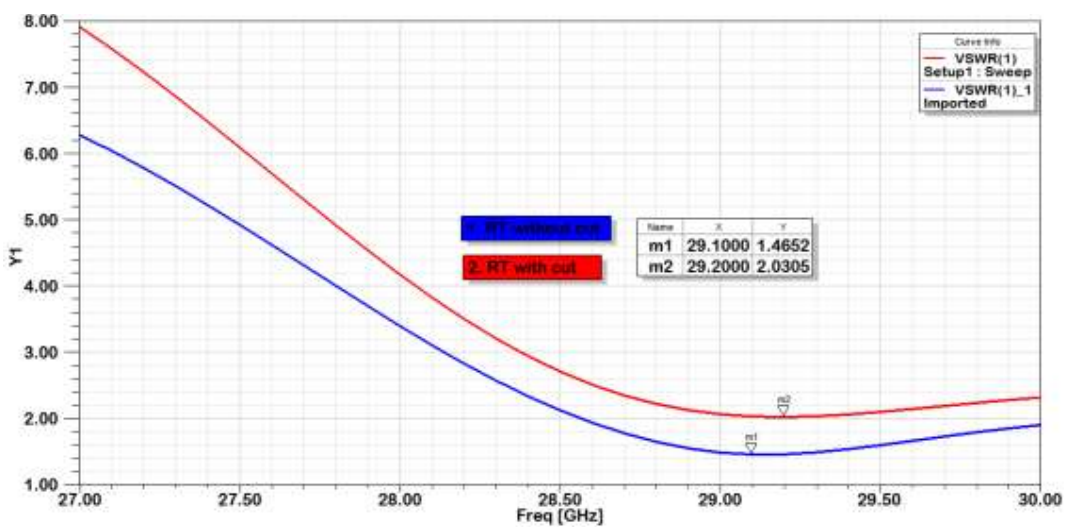


Figure 4. 32: VSWR of four element microstrip patch antenna for RT-duroid 5880

4.10.2 VSWR of four element microstrip patch antenna for FR 4

The designed antenna of four element patch; FR 4 with cut has a good VSWR that is 1.76 at 28.2 GHz a resonant frequency.

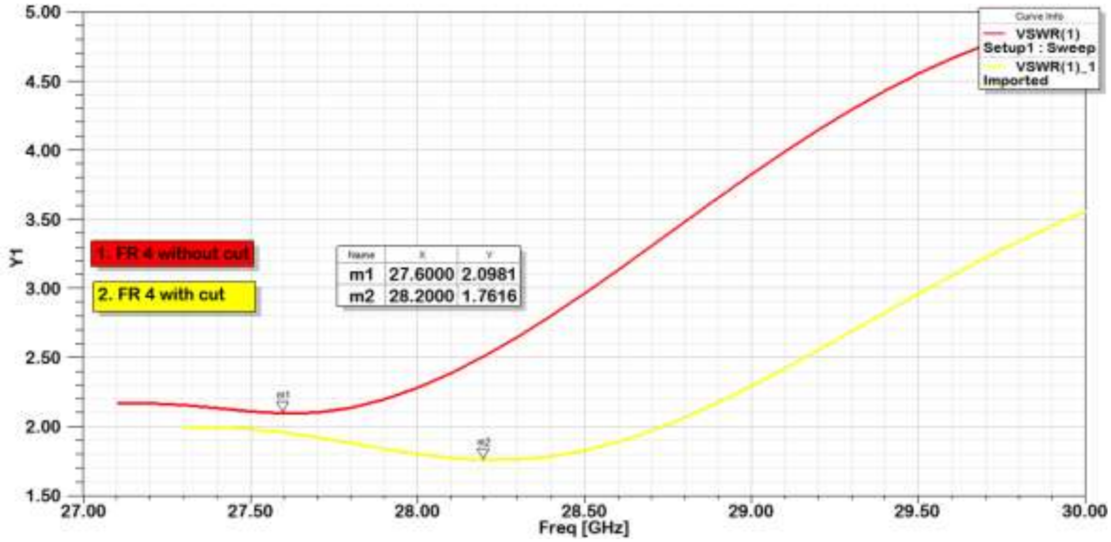


Figure 4. 33: VSWR of four element microstrip patch antenna for FR 4

4.10.3 VSWR of four element microstrip patch antenna for Mica

The designed antenna of four element patch; Mica without cut has a good VSWR that is 1.12 at 27.4 GHz a resonant frequency.

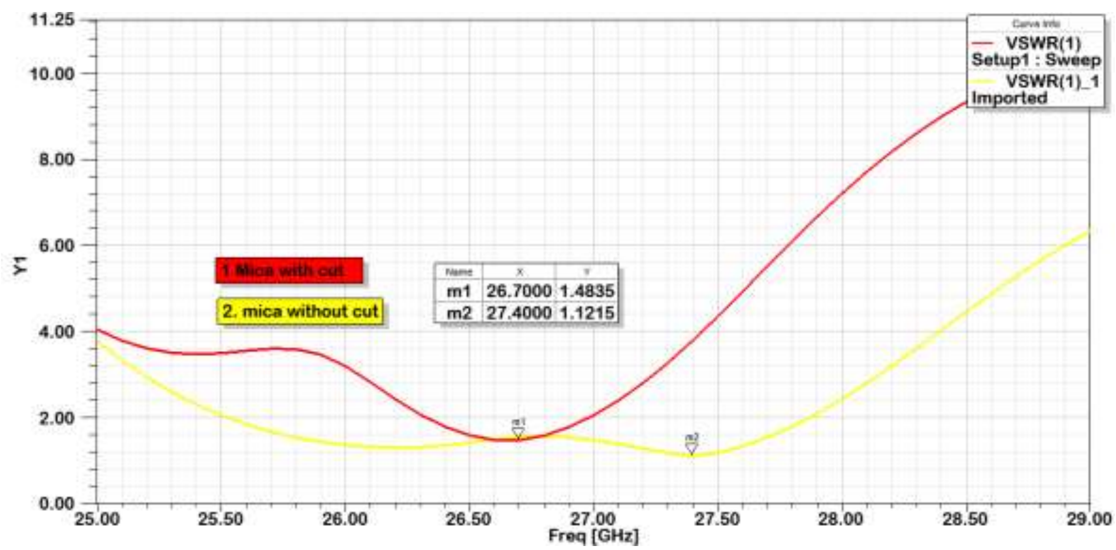
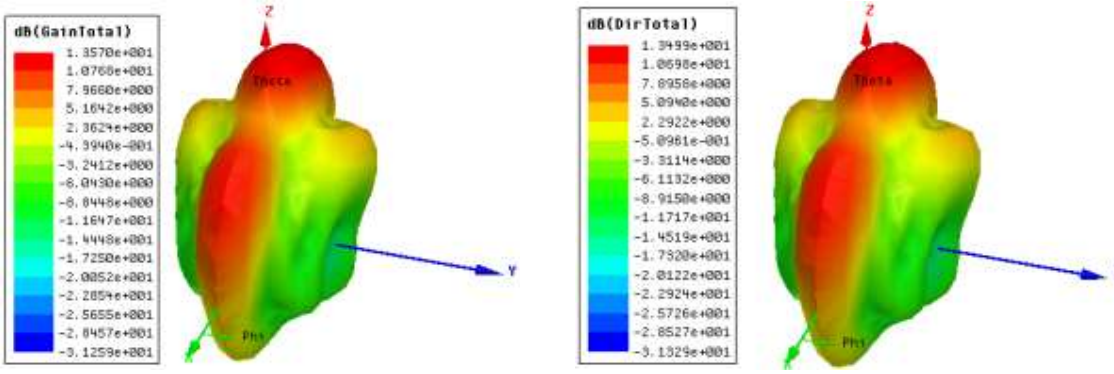


Figure 4. 34: VSWR of four element microstrip patch antenna for Mica

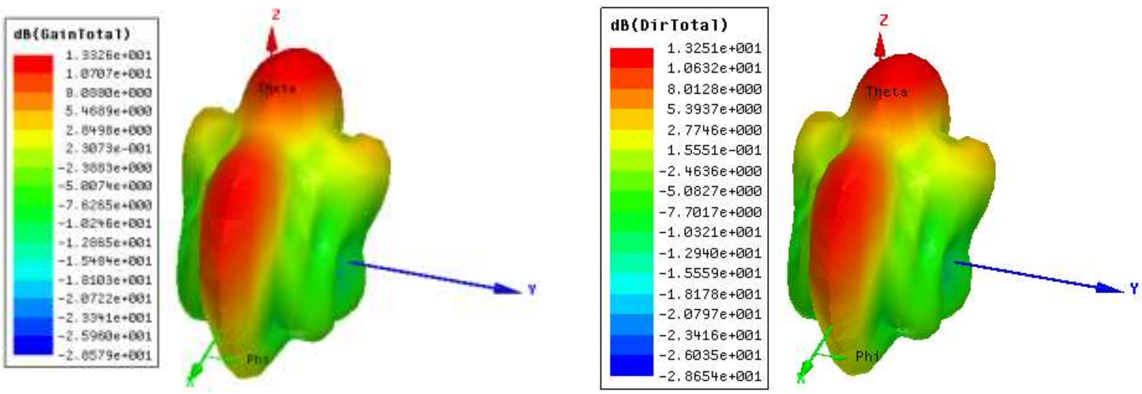
4.11 Gain and Directivity of Four Element Microstrip Patch Antenna Array

4.11.1 Gain and directivity of four element microstrip patch antenna for RT-duroid 5880

The higher gain and directivity obtained from the four element patch without one director, which is 13.57 dB and 13.5 dB at 29.1 GHz operating frequency respectively.



a. Gain and directivity of four element patch without cut

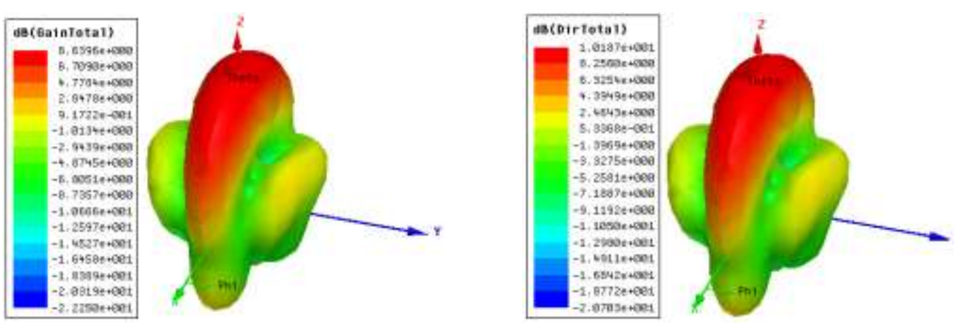


b. Gain and directivity of four element patch with cut

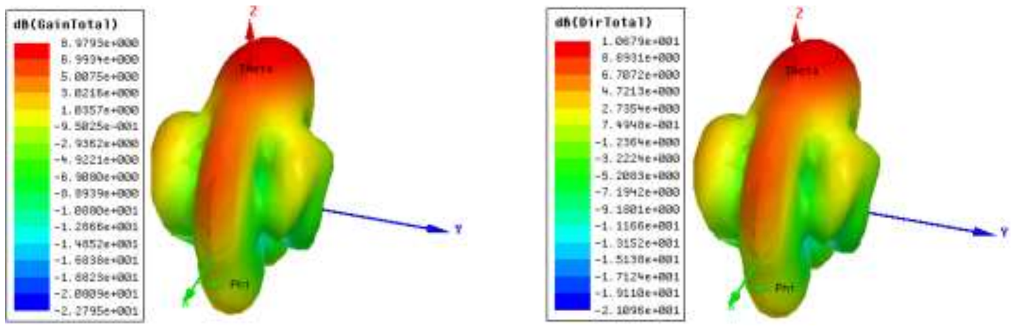
Figure 4. 35: Gain and directivity of four element microstrip patch antenna for RT-duroid 5880

4.11.2 Gain and directivity of four element microstrip patch antenna for RF 4

The higher gain and directivity obtained from the four element patch with one director, which is 6.03 dB and 7.15 dB at 28.6 GHz operating frequency respectively.



a. Gain and directivity of four element patch without cut

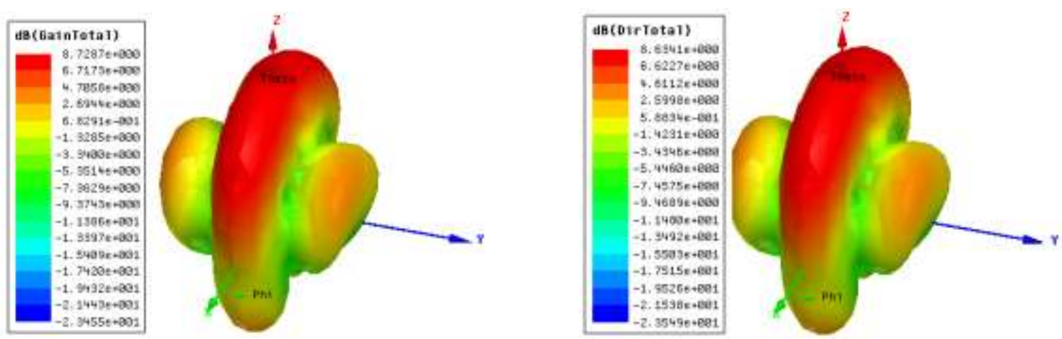


b. Gain and directivity of four element patch with cut

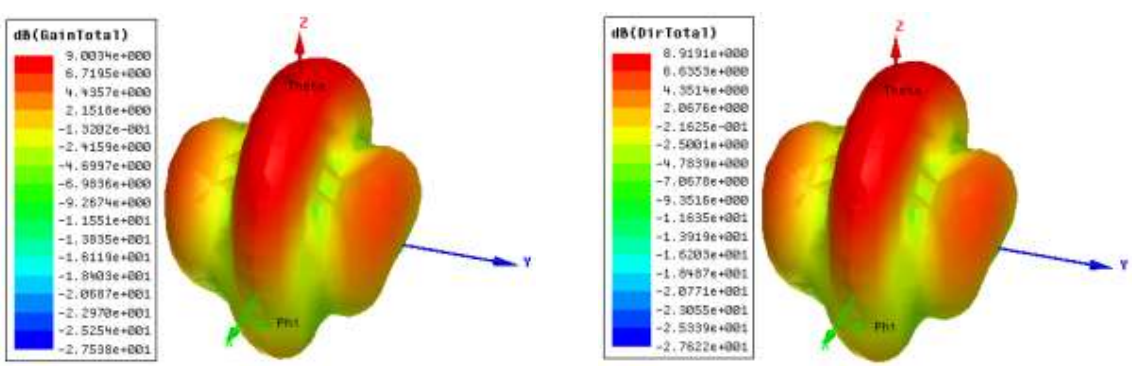
Figure 4. 36: Gain and directivity of four element microstrip patch antenna for FR4

4.11.3 Gain and directivity of four element microstrip patch antenna for Mica

The higher gain and directivity obtained from the four element patch with cut, which is 6.76 dB and 6.66 dB at 28 GHz operating frequency respectively.



a. Gain and directivity of four element patch without cut



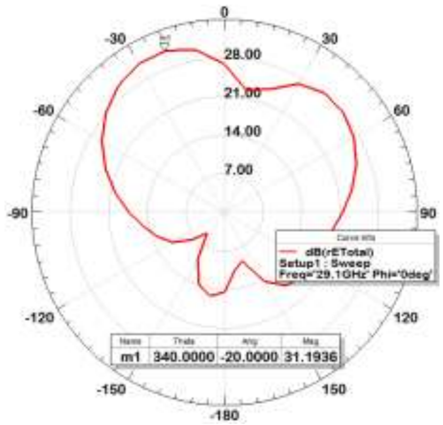
b. Gain and directivity of four element patch with cut

Figure 4. 37: Gain and directivity of four element microstrip patch antenna for FR4

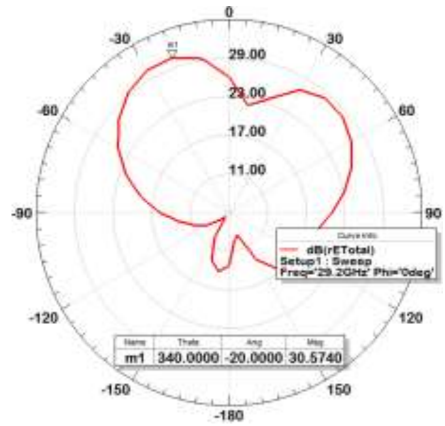
4.12 Radiation Pattern of Four Element Microstrip Patch Antenna Array

4.12.1 Radiation pattern of four element microstrip patch antenna for RT-duroid 5880

The main lobe direction radiation pattern of four element patch without cut is -40^0 with 27.26 dB magnitude at 29.1 GHz operating frequency.



a. Radiation pattern without cut

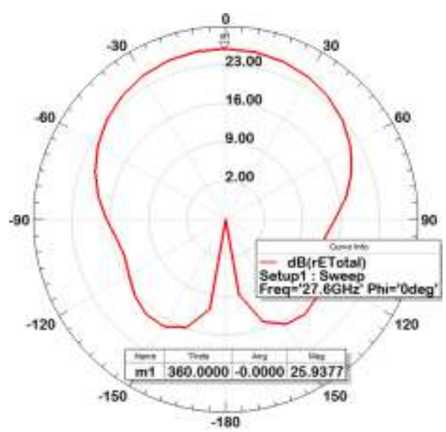


b. radiation pattern with cut

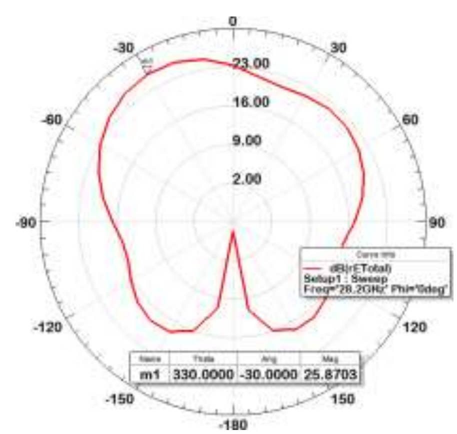
Figure 4. 38: Radiation pattern of four element microstrip patch antenna for RT-duroid 5880

4.12.2 Radiation pattern of four element microstrip patch antenna for FR 4

The main lobe direction radiation pattern of four element patch with cut is 20^0 with 23.69 dB magnitude at 28.3 GHz operating frequency.



a. Radiation pattern without cut

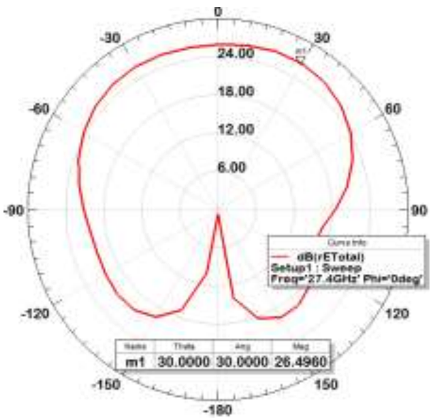


b. Radiation pattern with cut

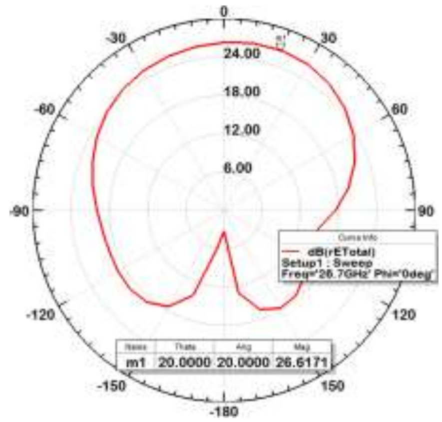
Figure 4. 39: Radiation pattern of four element microstrip patch antenna for FR 4

4.12.3 Radiation pattern of four element microstrip patch antenna for Mica

The main lobe direction radiation pattern of four element patch without cut is 20^0 with 24.46 dB magnitude at 28.3 GHz operating frequency.



a. Radiation pattern without cut

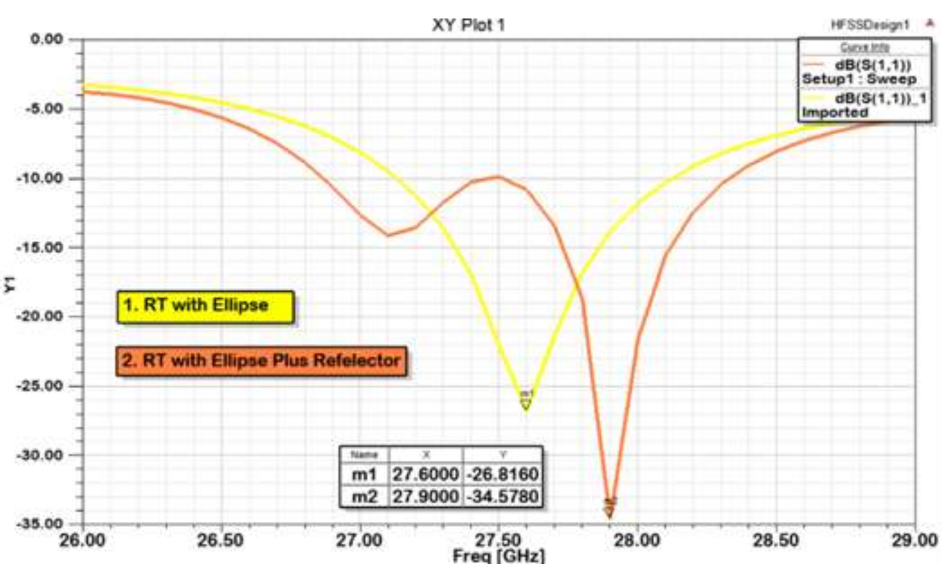


b. radiation pattern with cut

Figure 4. 40: Radiation pattern of four element microstrip patch antenna for FR 4

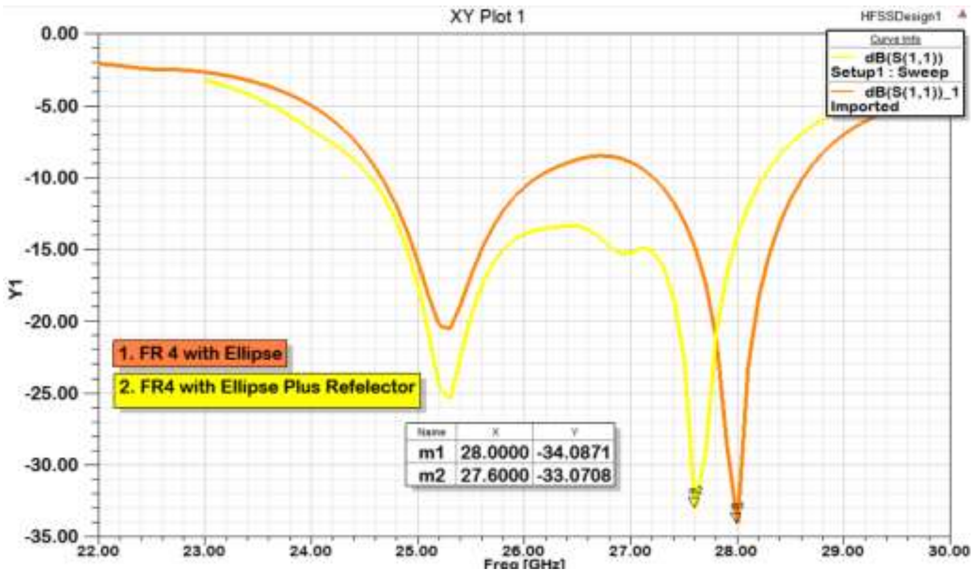
4.13 Return Loss of Four Element Microstrip Patch Antenna Array with Modification

The designed antenna of four element patch; RT-duroid 5880 with ellipse and reflector has a good return loss that is -34.58 dB at 27.9 GHz a resonant frequency.



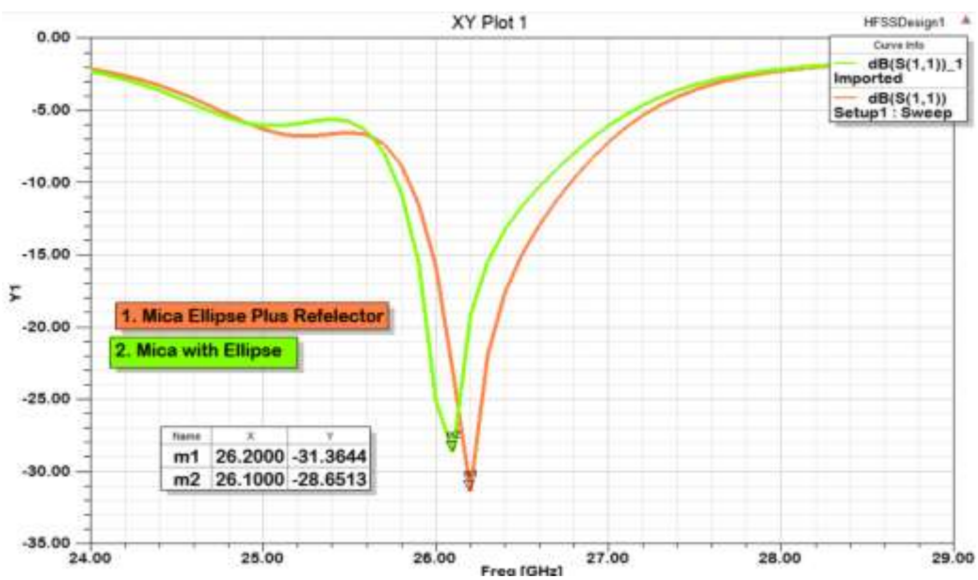
a. Return loss of four element patch of RT duroid with modification

The designed antenna of four element patch; FR4 with ellipse has a good return loss that is -34.08 dB at 28 GHz a resonant frequency.



a. Return loss of four element patches of FR4 with modification

The designed antenna of four element patch; Mica with ellipse and reflector has a good return loss that is -31.36 dB at 26.2 GHz a resonant frequency.

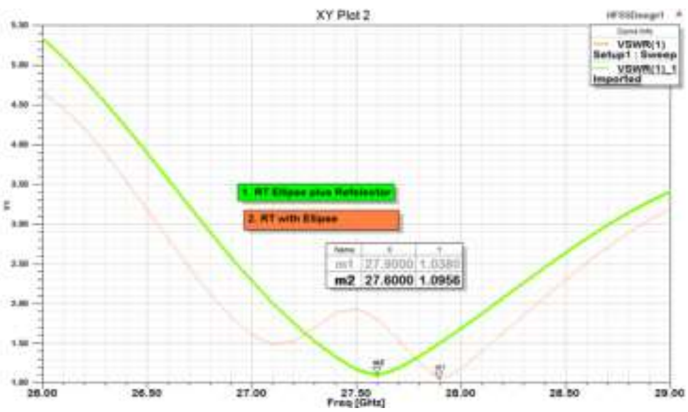


b. Return loss of four element patches of Mica with modification

Figure 4. 41 Return Loss of Four Element Microstrip Patch Antenna Array with Modification

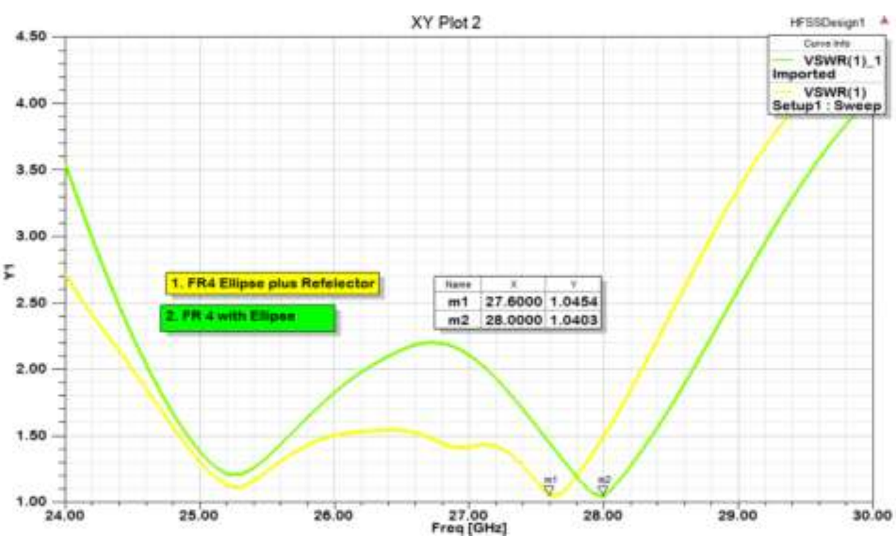
4.14 VSWR of Four Element Microstrip Patch Antenna Array with Modification

The designed antenna of four element patch; RT duroid with ellipse has a good VSWR that is 1.03 at 27.9 GHz a resonant frequency.



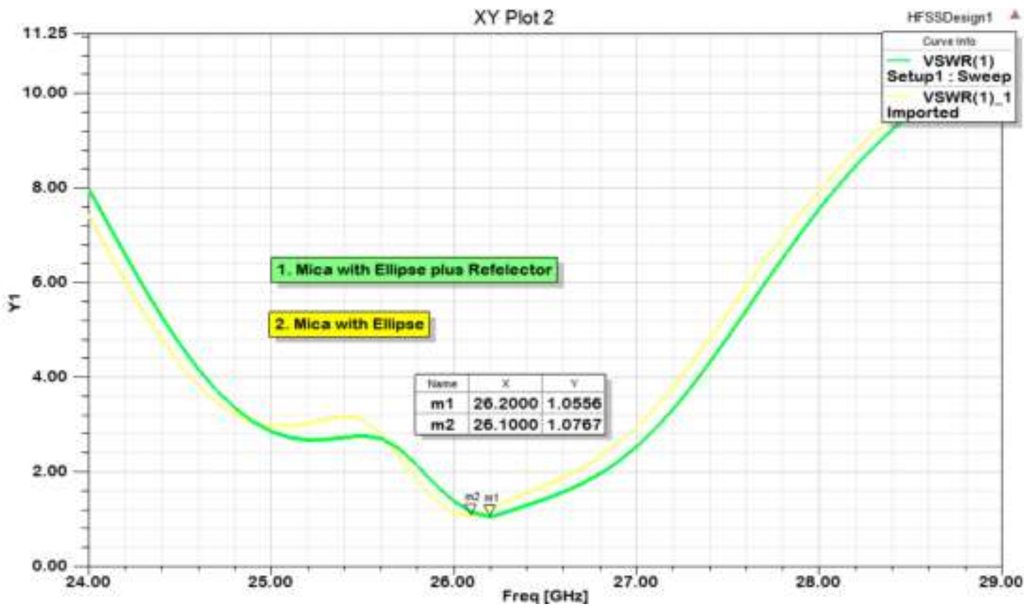
a. VSWR of four element patch of RT duroid with modification

The designed antenna of four element patch; FR4 with ellipse has a good VSWR that is 1.04 at 28 GHz a resonant frequency.



b. VSWR of four element patches of FR4 with modification

The designed antenna of four element patch; Mica with ellipse and reflector has a good VSWR that is 1.05 at 26.2 GHz a resonant frequency.

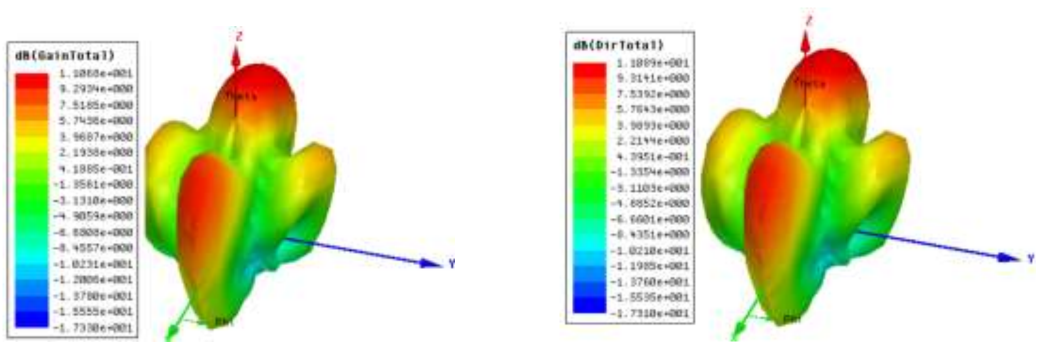


c. VSWR of four element patches of Mica with modification

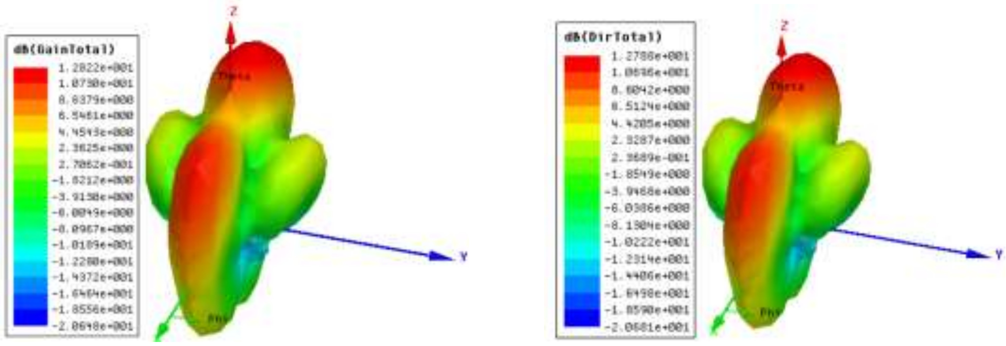
Figure 4. 42 VSWR of Four Element Microstrip Patch Antenna Array with Modification

4.15 Gain and Directivity of Four Element Microstrip Patch Antenna Array with Modification

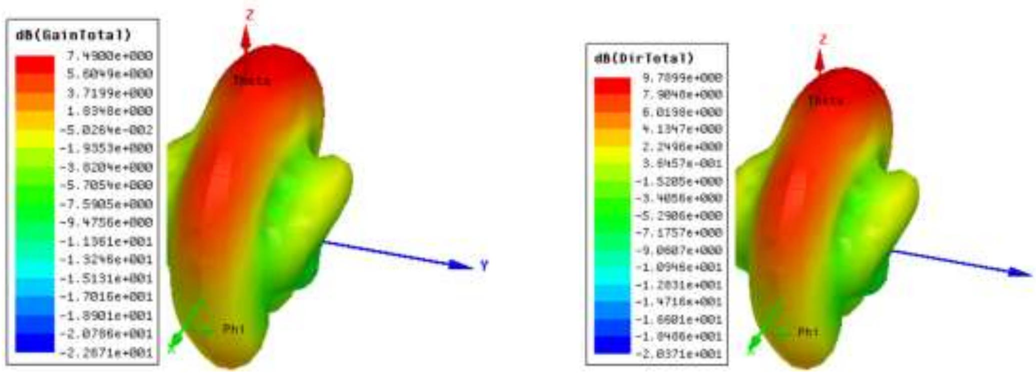
The higher gain and directivity obtained from the four-element patch with modification array antenna on RT duroid with ellipse, which is 12.82 dB and 12.79 dB at 27.6 GHz operating frequency respectively.



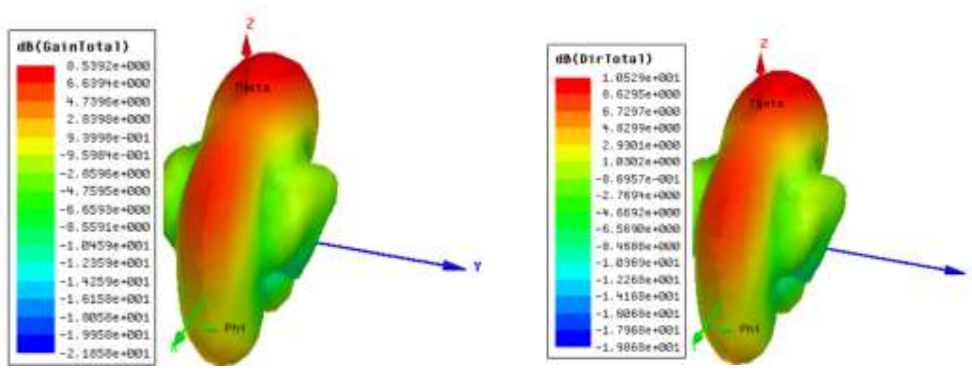
a. Gain and directivity of four element patch of RT duroid with Ref.



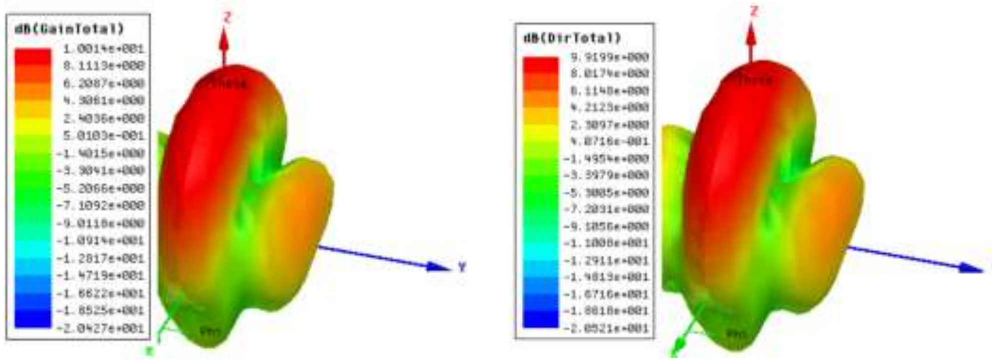
b. Gain and directivity of four element patch of RT duroid with ellipse



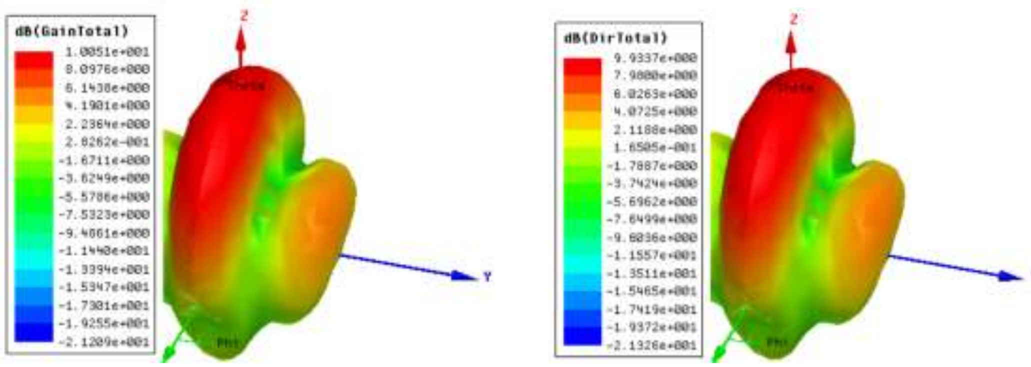
c. Gain and directivity of four element patches of FR4 with Ref.



d. Gain and directivity of four element patch of FR4 with ellipse



e. Gain and directivity of four element patches of Mica with Ref.

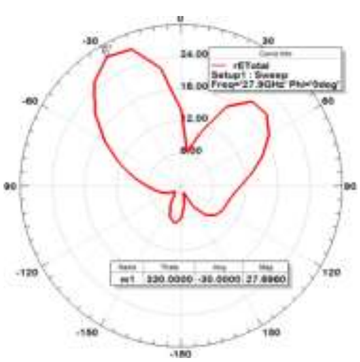


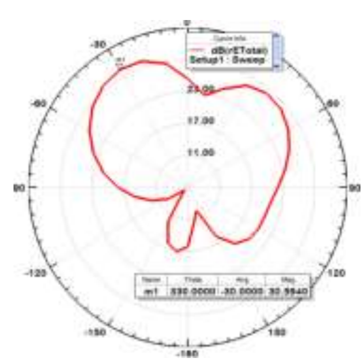
f. Gain and directivity of four element patch of Mica with ellipse

Figure 4. 43 Gain and Directivity of Four Element Microstrip Patch Antenna Array with Modification

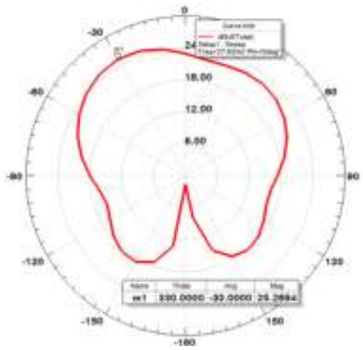
4.16 Radiation Pattern of Four Element Microstrip Patch Antenna Array with Modification

The main lobe direction radiation pattern of four element patch with modification is between 330^0 and 20^0.

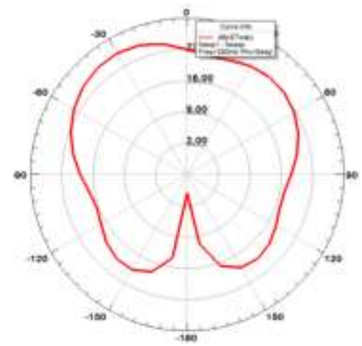




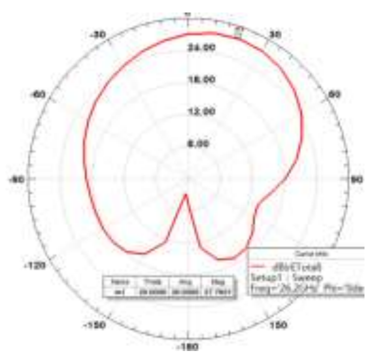
a. Radiation pattern of RT duroid with Ref. b. Radiation pattern of RT duroid with ellipse



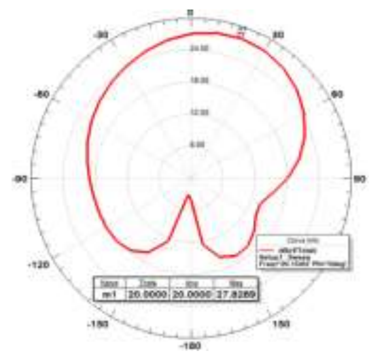
c. Gain and directivity of FR4 with Ref.



d. Radiation pattern of FR4 with ellipse



e. Radiation pattern of Mica with Ref.



f. Radiation pattern of Mica with ellipse

Figure 4. 44 Radiation Pattern of Four Element Microstrip Patch Antenna Array with Modification

Table 4. 1: Antenna parameters of Four element Microstrip Patch Antenna Array with Modification

Material	**Freq. GHz**	**S11 dB**	**VSWR**	**U. freq. GHz**	**L. freq. GHz**	**BW MHz**	**Gain dB**	**Dire. dB**	**Effic. %**
RT + Ellipse	27.6	26.82	1.09	28.1	27.1	1000	12.82	12.79	99.77
RT + Reflector	27.9	34.57	1.03	28.5	27.5	900	11.11	11.12	99.86
FR4 + Ellipse	28.0	34.08	1.04	28.6	27.3	1300	8.54	10.52	81.18
FR4 + Reflector	27.6	33.07	1.04	28.3	24.6	3700	7.49	9.78	76.58
Mica + Ellipse	26.1	28.65	1.07	26.7	25.8	900	10.05	9.94	99.00
Mica + Reflector	26.1	31.36	1.05	26.8	25.8	1000	10.01	9.92	99.10

The antenna designs analyzed in Table 4.1 exhibit favorable characteristics across various performance metrics. In terms of return loss and VSWR, all designs demonstrate low reflection coefficients and good impedance matching, with VSWR values close to 1. Operating within a frequency range of 26.1 GHz to 28.0 GHz, the antennas offer bandwidths ranging from 900 MHz to 3700 MHz, with wider bandwidths typically associated with FR4 material configurations. Gain values between 7.49 dB and 12.82 dB are observed, with higher gains seen in RT material configurations with the Ellipse modification. Directivity values ranging from 9.78 dB to 12.79 dB indicate the antennas' ability to focus radiation directionally. Efficiency levels vary from 76.58% to 99.86%, with RT material and Reflector modification antennas exhibiting higher efficiency. Comparatively, the RT material with Ellipse modification design showcases superior performance in efficiency, gain, directivity, return loss, and VSWR. While the FR4 material with Reflector modification provides a broader bandwidth, it compromises on gain and directivity.

4.17 Validation of Simulated Results with Related Works

When comparing the proposed microstrip patch antenna array for 5G applications with existing array antenna designs, it becomes evident that each array structure has unique design objectives and specifications. The proposed microstrip patch antenna array aims to provide wideband coverage suitable for 5G applications, focusing on achieving high data rates and low latency. In contrast, existing array antenna designs may prioritize different aspects such as beamforming capabilities, polarization diversity, or size constraints.

Upon analyzing the data presented in table 4.2, it becomes apparent that the proposed microstrip patch antenna array outperforms existing array designs in terms of wideband operation. The related antenna design specifications highlight the superior performance of the proposed array in achieving high gain, low return loss, and efficient radiation characteristics across various frequency ranges relevant to 5G communication systems.

Table 4. 2 Comparison of Proposed Antenna with Related Antenna Designs

Author (Reference)	**Material used**	**Freq. GHz**	**S11 dB**	**VSWR**	**BW MHz**	**Gain dB**
Parese Yugandhar1, 2022	Rogers RT	28.1	39.42	1.02	2000	10.85
Nail Alaoui, 2023	Rogers RT	28.0	14.58	1.48	954	12.40
Sattar O. et al, 2021	FR4	28.0	25.44	1.11	616	6.90
Ali A. et al., 2020	Rogers RT	27.8	33.60	1.04	2700	8.43
Vinod Kumar, 2021	FR4	29.0	26.20	1.10	-	11.46
Amrutha1.el al, 2017	FR4	25.5	14.46	1.33	-	7.10
Mulugeta T. et al, 2021	FR4	28.0	38.86	1.02	1046	7.58
Kiran1. el al, 2018	Rogers RT	28.3	20.84	1.58	350	2.6
Sohel Rana, 2022	Rogers RT	28.0	38.43	1.02	3464	8.2
Mohamed B, 2018	FR4	27.5	21.4	1.34	-	11.2
Rana et al., 2022	Rogers RT	28.0	32.15	1.14	2848	8.07
Okoro et al., 2021	FR4	28.2	20.03	1.22	2110	5.23
Tung et al., 2020	Rogers RT	27.8	14.02	1.48	660	8.65
This Works	RT + Ellipse	27.6	26.82	1.09	1000	12.82
	RT + Reflector	27.9	34.57	1.03	900	11.11
	FR4 + Ellipse	28.0	34.08	1.04	1300	8.54
	FR4 + Reflector	27.6	33.07	1.04	3700	7.49
	Mica + Ellipse	26.1	28.65	1.07	900	10.05
	Mica + Reflector	26.1	31.36	1.05	1000	10.01

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the research on the design and analysis of a microstrip patch antenna array for 5G applications has effectively demonstrated the potential for creating high-performance antenna systems suited for next-generation communication networks. By comparing the array's design parameters and configurations, notable improvements in gain and bandwidth were achieved, fulfilling the demanding requirements of 5G technology. Simulation results validated the proposed design's capability to offer reliable and efficient communication for 5G networks. This study provides a strong foundation for future research and advancements in antenna technologies for upcoming wireless communication systems.

5.2 Recommendation

Building on the findings of this research, several directions for future studies in antenna design for 5G applications can be suggested. First, further research could involve the development and testing of practical prototypes of the microstrip patch antenna array to assess its performance in real-world conditions. Experimental tests and measurements would offer critical insights into the antenna's actual performance and allow for design adjustments to optimize its functionality. In addition, exploring different materials and fabrication methods for the antenna elements could improve both efficiency and miniaturization, addressing the evolving needs of 5G communication systems. Collaborative efforts with industry partners could also accelerate the integration of cutting-edge antenna technologies into commercial 5G networks, driving innovation and supporting the deployment of high-performance communication solutions. In conclusion, ongoing research and development in antenna design are crucial to meet the increasing demands of 5G applications and ensure the creation of reliable and efficient wireless communication systems.

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