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Planar Antennas for Wireless Local Area Networks by Python Scripting

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Abstract

Printed antennas present an essential part of wireless communication networks. They are a widely-used type of integrated antennas that of a patch on the top and of a grounded substrate. Designing such kind of antennas faces always major limitations and suggests high performances that make it real topic for research and investigation. In this regard, this research study aims to investigate and develop Planar PIFA designs for wireless local area networks (WLAN) using Python Scripting as a smart solution for effective electromagnetic modeling and optimization to provide a highly performance design.

Key words: Printed Antennas, WLAN, HFSS, Python Scripting, Design and Optimization.

Résumé

Les antennes imprimées constituent une partie essentielle des réseaux de communication sans fil. Il s'agit d'un type d'antennes intégrées largement utilisé, constitué d'un patch sur le dessus et d'un substrat mis à la terre. La conception de ce type d'antennes se heurte toujours à des limites majeures et suggère des performances élevées qui en font un véritable sujet de recherche et d'investigation. À cet égard, cette étude de recherche vise à étudier et à développer des conceptions Planar PIFA pour les réseaux locaux sans fil (WLAN) en utilisant Python Scripting comme solution intelligente pour une modélisation et une optimisation électromagnétiques efficaces afin de fournir une conception hautement performante.

Mots clés: Antennes imprimées, WLAN, HFSS, Scripting Python, Conception et Optimisation.

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Dedications

To my parents, whose unwavering love, encouragement, and sacrifices have been the cornerstone of my academic pursuits. Your belief in me has been my guiding light, propelling me forward even when the path seemed daunting. This thesis stands as a testament to your endless support and the values you've instilled in me. I dedicate this work to you with deepest gratitude and love.

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List of Abbreviations

AES	Advanced Encryption Standard.
AP	Access Point.
ARPANET	Advanced Research Projects Agency Network.
BGP	Border Gateway Protocol.
BPSK	Binary Phase Shift Keying.
BW	Bandwidth.
CRC	Cyclic Redundancy Check.
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance.
DEC	Digital Equipment Corporation.
DHCP	Dynamic Host Configuration Protocol.
FEC	Forward Error Correction.
FSK	Frequency Shift Keying.
FDM	Frequency Division Multiplexing.
HFSS	High-Frequency Structural Simulator.
IEEE	Institute of Electrical and Electronics Engineers.
IoT	Internet of Things.
IP	Internet Protocol.
ISO	International Standards Organization.

LAN	Local Area Network.
LOS	Line of Sight.
MAC	Medium Access Control.
MAN	Metropolitan Area Network.
MIMO	Multiple Input/ Multiple Output.
MPA	Microstrip Patch Antenna.
NFC	Near Field Communication.
NLOS	Non-Line of Sight.
OFDM	Orthogonal Frequency Division Multiplexing.
OSI	Open Systems Interconnection.
OSPF	Open Shortest Path First.
P2MP	Point-to-Multipoint.
PAN	Personal Area Network.
PCB	Printed Circuit Boards.
PDN	Public Data Networks.
PIFA	Planar Inverted-F Antennas.
PY	Python Scripting.
QAM	Quadrature Amplitude Modulation.
QoS	Quality of Service.
RF	Radio Frequency.

RFID	Radio-Frequency Identification.
RIP	Routing Information Protocol.
RL	Return Loss.
RP	Radiation Pattern.
SSL	Secure Sockets Layer.
TCP	Transmission Control Protocol.
TCP/IP	Transmission Control Protocol/Internet.
TDM	Time Division Multiplexing.
TLS	Transport Layer Security.
UDP	User Datagram Protocol.
VSWR	Voltage Standing Wave Ration.
Wi-Fi	Wireless Fidelity.
WiMAX	Worldwide Interoperability for Microwave Access.
WLAN	Wireless Local Area Network.
WPA	Wi-Fi Protected Access.

General Introduction

Microwave technology, operating within the electromagnetic spectrum from 1 gigahertz (GHz) to 300 gigahertz (GHz), serves as the backbone for various communication systems such as wireless communication, radar, and satellite communication. In parallel, Wireless Local Area Networks (WLANs) leverage microwave frequencies, typically in the 2.4 GHz and 5 GHz bands, to enable wireless connectivity for devices within localized areas, revolutionizing modern networking. These WLANs rely on specialized antennas, often employing planar technology, which involves the fabrication of flat, two-dimensional structures like printed circuit boards (PCBs) and transmission lines. Planar technology offers advantages such as compact size, cost-effectiveness, and compatibility with mass production techniques, making it ideal for WLAN antenna design. These antennas play a pivotal role in determining WLAN coverage, range, and performance, with various types like omnidirectional and directional antennas tailored for different deployment scenarios. As WLAN technology evolves, antennas continue to advance in design, efficiency, and miniaturization to meet the increasing demands for high-speed and reliable wireless connectivity in diverse applications. [1]

The microstrip patch antennas are widely used due to their advantages like planar structure, low profile, and ease for manufacturing purpose and cost effectiveness. The performance and advantages of microstrip patch antennas such as low weight, low profile, and low cost made them the perfect choice for communication systems engineers. They have the capability to integrate with microwave circuits and therefore they are very well suited for applications such as cell devices, WLAN applications, navigation systems and many others. [2]

In this regard, this study aims to develop a highly performance Planar Antennas for Wireless Local Area Networks (WLAN) using Python Scripting (PY) as a smart solution for effective electromagnetic modeling and optimization

The goals for making Planar Antennas using Python are straightforward. First, we want to create antenna designs that work well for Wireless Local Area Networks. Then, we'll use Python to make slots in the patch of antenna in order to optimize performance of antenna and then check how these antennas perform and make sure they match our expectations. After that, we'll fine-tune the designs based on what we find. Finally, we'll use Python to visualize the data we get from testing, so we can make better decisions as we go along. Overall, we aim to use Python to make the whole process of designing and improving Patch Antennas easier and more efficient.

The study is organized into four chapters. Under the first chapter we have discussed the history of computing networks of Wireless Networks, Types of Wireless Networks, Evolution and advantages of WiMAX. The second chapter will provide Fundamentals of Antennas and their types, also main Parameters and Characteristics. The third chapter includes Planar Antennas advances and limitations, Types of Patch Antennas and feedings methods, Microstrip Antennas Designs. The last chapter is allocated to the simulation and results in which a high performance PIFA antenna is designed for wireless local area networks (WLAN) using Python Scripting.

CHAPTER 1

WIRELESS NETWORKS

1.1. History of computing networks:

1.1.1. The beginnings of computing networks:

Computer networking as we know it today may be said to have gotten its start with the ARPANET development in the late 1960s and early 1970s. Prior to that time there were computer vendor" networks" designed primarily to connect terminals and remote job entry stations to a mainframe. But the notion of networking between computers viewing each other as equal peers to achieve "resource sharing" was fundamental to the ARPANET design. The other strong emphasis of the ARPANET work was its reliance on the then novel technique of packet switching to efficiently share communication resources among" burst" users, instead of the more traditional message or circuit switching. [3]

Although the term "network architecture" was not yet widely used, the initial ARPANET design did have a definite structure and introduced another key concept: protocol layering, or the idea that the total communications functions could be divided into several layers, each building upon the services of the one below. The original design had three major layers, a network layer, which included the network access and switch-to-switch (IMP-to-IMP) protocols, a host-to-host layer (the Network Control Protocol (NCP), and a "function-oriented protocol" layer, where specific applications such as file transfer, mail, speech, and remote terminal support were provided. [4]

Similar ideas were being pursued in several other research projects around the world, including the Cyclades network in France [5], the National Physical Laboratory Network in England [6], and the Ethernet system [7] at Xerox PARC in the USA. Some of these projects focused more heavily on the potential for high-speed local networks such as the early 3-Mbps Ethernet. Satellite and radio channels for mobile users were also a topic of growing interest.

1.1.2. Development of computing networks:

By 1973 it was clear to the networking vanguard that another protocol layer needed to be inserted into the protocol hierarchy to accommodate the interconnection of diverse types of individual networks. Cerf and Kahn published their seminal paper describing such a scheme [8], and development of the new Internet Protocol (IP) and Transmission Control Protocol (TCP) to jointly replace the NCP began. Similar work was being pursued by other groups meeting in the newly formed IFIP WG 6.1, called the Internetwork Working Group. [9]

The basis for the network interconnection approach developing in this community was to make use of a variety of individual networks each providing only a simple "best effort" or "datagram" transmission service. Reliable virtual circuit services would then be provided on an end-to-end basis with the TCP (or similar protocol) in the hosts. During the same time period, public data networks (PDNs) were emerging under the auspices of CCITT, aimed at providing more traditional virtual circuit types of network service via the newly defined X.25 protocol. The middle and late 1970s saw networking conferences dominated by heated debates over the relative merits of circuit versus packet switching and datagrams versus X.25 virtual circuits. The computer vendors continued to offer their proprietary networks, gradually supporting the new X.25 service as links under their own protocols. Digital Equipment Corporation (DEC) was the notable exception, adopting the research community approach of peer-to-peer networking at an early date, and coming out with its own new suite of protocols (DECNET). [10]

By the late 1970s, a new major influence was emerging in the computer network community. The computer manufacturers realized that multivendor systems could no longer be avoided, and began to take action to satisfy the growing user demand for interoperability. Working through their traditional international body, the ISO, a new group (SC16) was created to develop standards in the networking area. Their initial charter was to define an explicit "architecture" for "Open Systems Interconnection" (OSI).

By the early 1980s there were three major players in the networking game: the ARPANET-style research community, the carriers with their PDNs in CCITT, and the manufacturers in ISO. The conference circuit became more acrimonious, with the research community lambasting the slow progress, ponderousness (7 layers!), lack of experimental support, and all-inclusiveness (five classes of transport protocol) of the ISO workers.

Ethernet continued dominance in LAN technologies in the 1990s, as it continued to eclipse its alternatives. With computer networks facing rapid growth at the time, Ethernet of greater speeds was needed to satisfy the needs of bandwidth-hungry applications. As a result, the first full-duplex Ethernet with speeds of 20Mbps was introduced in 1992. A standard full-duplex Ethernet was in the works since 1995 and was finished in 1997.

In 1992, an Ethernet bus known as the Grand Junction Networks commercial Ethernet bus was introduced. It achieved speeds of 100Mbps. This advancement drove the 802.3 group to introduce the 802u 100BaseT Fast Ethernet standard. The standard transmitted data at 100Mbps over fiber-optic and twisted-pair cables.

After the 100BaseT Fast Ethernet standard, sights were set on Gigabit Ethernet, which is the 1,000Mbps Ethernet version. It came into use in 1999, and due to its considerable improvement in speed in comparison to Fast Ethernet, it replaced Ethernet in wired local networks. 1997 saw the introduction of the first 802.11 Wi-Fi standards. It provided speeds of up to 2Mbps. It was made official in 1999, with the capability to reach transmission speeds of 25Mbps and used the 5GHz frequency band. [11]

Since the demands for Wi-Fi and Ethernet continued to increase over the years, networking technology has continued to evolve. Today, networking is defined by the need for low-latency and high-bandwidth network technologies.

The most prominent technologies associated with networking today include 5G and Wi-Fi 6, augmented reality, virtual reality, machine learning, artificial intelligence, cloud computing, the Internet of Things, software-defined wide area networking and more.

1.2. Wireless Networks:

A wireless network is nothing but a wireless media connecting via Radio waves. A wireless local-area network (LAN) uses radio waves to connect devices such as laptops to the Internet and to business network and its applications. When one connect a laptop to a Wi-Fi hotspot at a cafe, hotel, airport lounge, or other public place, a wired network connects devices to the Internet or other network using cables. In the past, some believed wired networks were faster and more secure than wireless networks. But continual enhancements to wireless networking standards and technologies have eroded those speed and security differences. Wireless technologies employ radio waves and/or microwaves to maintain communication channels between computers. Knowing the basics can be very helpful when configuring a network and troubleshooting problems.

Wireless networks are computer networks that are not connected by cables of any kind. The use of a wireless network enables enterprises to avoid the costly process of introducing cables into buildings or as a connection between different equipment locations. The bases of wireless systems are radio waves, an implementation that takes place at the physical level of network structure. [12]

1.2.1. Types of Wireless Network:

Wireless technologies have revolutionized the way we communicate and connect devices over short and long distances. From Personal Area Networks (PANs) to Metropolitan Area Networks (MANs), each type of wireless network serves a distinct purpose, catering to various needs and applications. We'll delve into the characteristics, applications, and advancements in PANs, LANs, and MANs.

1.2.1.1. Personal Area Network (PAN):

A PAN is the smallest type of wireless network, typically covering a range of a few meters to tens of meters. It enables communication between personal devices such as smartphones, laptops, tablets, and wearable gadgets (figure 1.1). Bluetooth and Near Field Communication (NFC) are common technologies used for establishing PANs. PANs facilitate convenient data sharing, device synchronization, and peripheral connectivity.

With the proliferation of Internet of Things (IoT) devices, PANs play a crucial role in enabling seamless interaction among smart appliances, wearable health monitors, and home automation systems. For example, Bluetooth PANs allow users to control smart home devices from their smartphones or tablets, offering convenience and efficiency. [13]

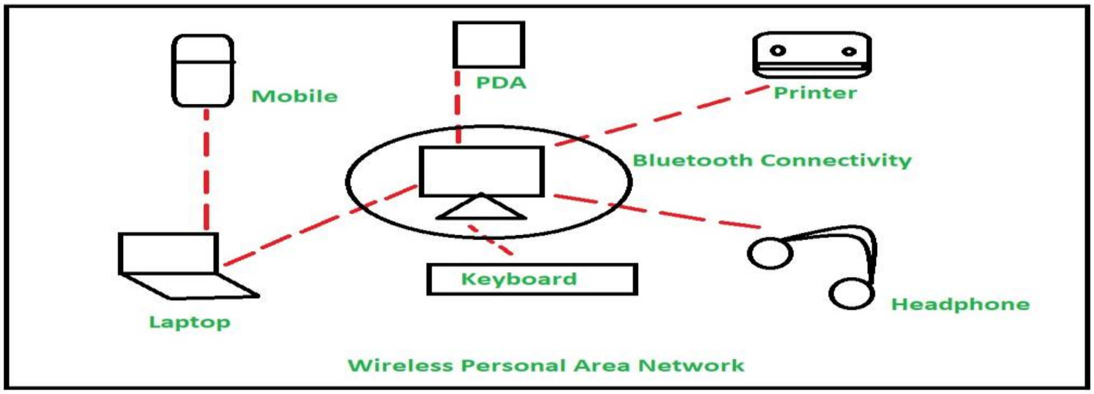


Figure 1.1: Wireless Personal Area Network.

1.2.1.2. Local Area Network (LAN):

LANs cover a larger geographical area compared to PANs, typically ranging from a few hundred meters to a few kilometers. These networks are commonly used in homes, and offices, schools, and other localized environments to interconnect computers, printers, servers, and other networked devices (figure 1.2). Wi-Fi, Ethernet, and Zigbee are popular technologies employed in LANs.

Wi-Fi, based on IEEE 802.11 standards, has become ubiquitous, providing wireless internet access and facilitating communication between devices within a LAN. Modern LANs support high-speed data transfer, multimedia streaming, and real-time collaboration, fostering productivity and connectivity in various settings. [14]

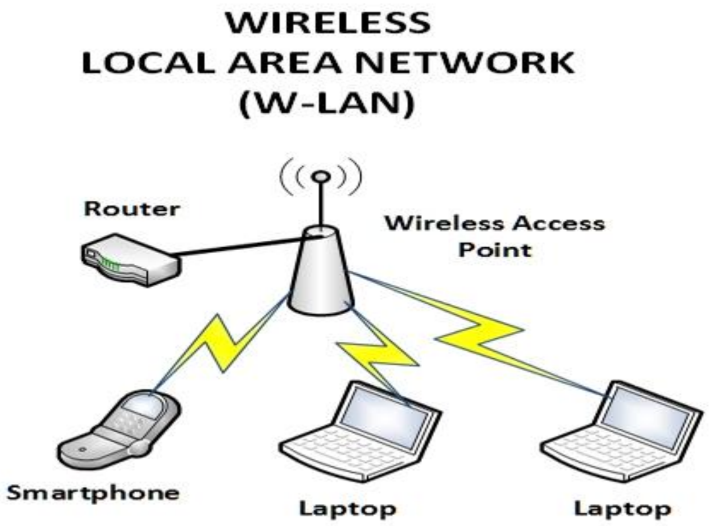


Figure 1.2: Wireless Local Area Network.

1.2.1.3. Metropolitan Area Network (MAN):

MANs cover a larger geographical area than LANs, typically spanning a city or a metropolitan region. These networks connect multiple LANs and serve as the backbone for delivering internet access, telecommunication services, and enterprise connectivity across urban areas (figure 1.3). Technologies such as WiMAX

(Worldwide Interoperability for Microwave Access) and LTE (Long-Term Evolution) are commonly used in MANs.

MANs play a crucial role in providing high-speed internet access to urban dwellers, supporting services like video streaming, VoIP (Voice over Internet Protocol), and cloud computing. Additionally, MANs facilitate interconnection between businesses, educational institutions, and government agencies, enabling efficient data exchange and collaboration over large distances. [15]

Figure 1.3: Metropolitan Area Network.

Advancements in wireless networking continue to drive innovation and transform connectivity across PANs, LANs, and MANs. Emerging technologies such as 5G, which promises ultra-fast speeds, low latency, and massive connectivity, are poised to revolutionize wireless communication further.

1.3. Wi-Fi Link:

Wi-Fi, an abbreviation for Wireless Fidelity, has become synonymous with wireless connectivity in today's digital age. Wi-Fi links refer to the wireless connections established between devices, allowing them to communicate and exchange data without the need for physical cables. These links form the backbone of wireless networks, enabling seamless internet access, data transfer, and communication across various devices and locations.

At its core, a Wi-Fi link operates based on radio frequency (RF) signals within the 2.4 GHz and 5 GHz bands. These signals are transmitted and received by devices equipped with Wi-Fi capabilities, such as smartphones, laptops, tablets, IoT devices, and Wi-Fi routers or access points. [15]

1.3.1. The establishment of a Wi-Fi link:

The process of establishing a Wi-Fi link involves several key steps:

a) Scanning and Discovery: Devices equipped with Wi-Fi capabilities scan the surrounding spectrum to discover available networks. This process involves probing for beacon frames emitted by nearby access points, enabling devices to ascertain network availability and characteristics.

b) Association and Authentication: Upon selecting a network, devices initiate the association process, wherein they authenticate themselves to the chosen access point. Authentication mechanisms, including pre-shared keys, enterprise authentication protocols (e.g., 802.1X), and WPA/WPA2, validate the device's credentials before granting network access.

c) Dynamic IP Assignment: Following successful authentication, devices are dynamically assigned IP addresses through protocols like DHCP (Dynamic Host Configuration Protocol). This allocation enables devices to engage in IP-based communication within the network, facilitating seamless data exchange.

d) Data Transmission and Reception: Wi-Fi links facilitate the exchange of data packets between devices and access points. Data frames, encapsulating user payloads, traverse the wireless medium employing modulation schemes like OFDM (Orthogonal Frequency Division Multiplexing) and error correction techniques to ensure reliable transmission.

e) Security and Encryption: To safeguard data integrity and confidentiality, Wi-Fi links employ robust encryption and security mechanisms. WPA2/WPA3 protocols, alongside encryption algorithms like AES (Advanced Encryption Standard), fortify Wi-Fi communications against unauthorized access and malicious interception. [16]

1.3.2. Interfaces of a Wi-Fi Link:

The interface of a Wi-Fi link encompasses the intricate interplay between various components and protocols, facilitating seamless wireless communication between devices. Understanding this interface is pivotal for optimizing Wi-Fi network performance, reliability, and security. [15]

Here, we delve into the key elements of the Wi-Fi link interface and their functions:

1.3.2.1. Physical Layer (PHY):

The PHY layer is responsible for transmitting and receiving radio signals over the air. It modulates digital data into analog signals for transmission and demodulates received signals back into digital data.

In Wi-Fi networks, the PHY layer operates within the 2.4 GHz and 5 GHz frequency bands, utilizing modulation techniques such as OFDM (Orthogonal Frequency Division Multiplexing) to transmit data efficiently. It also handles tasks like channel selection, signal modulation, and power management. [17]

1.3.2.2. Medium Access Control (MAC):

The MAC layer controls access to the wireless medium and manages the transmission of data frames between devices. It implements protocols such as CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) to avoid collisions and ensure fair access to the channel.

The MAC frame control format is shown in (Figure 1.4).

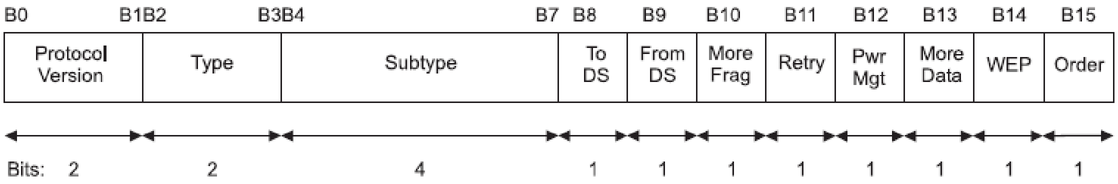


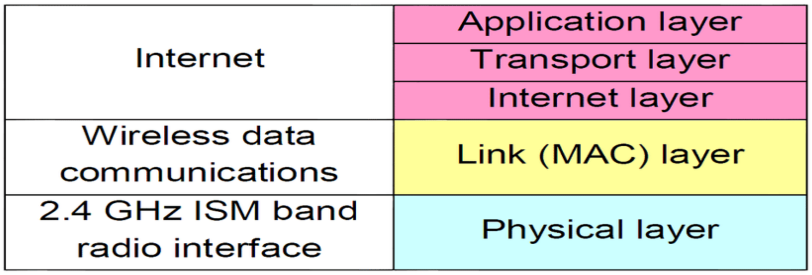
Figure 1.4: The MAC frame control format.

In Wi-Fi networks, the MAC layer coordinates the transmission of data frames between Wi-Fi devices and access points. It handles tasks like frame acknowledgment, fragmentation, and contention resolution. Additionally, it provides mechanisms for authentication, encryption, and QoS (Quality of Service) management. [17]

1.3.2.3. Wi-Fi Protocol Stack:

The Wi-Fi protocol stack consists of multiple layers, including PHY, MAC, and higher-layer protocols such as IP (Internet Protocol) and TCP (Transmission Control Protocol). It defines how data is transmitted, routed, and delivered within a Wi-Fi network. [15]

The Wi-Fi protocol stack follows the OSI (Open Systems Interconnection) model, with each layer performing specific functions related to data transmission and network communication. The PHY and MAC layers handle the physical and data link aspects of wireless communication, while higher-layer protocols manage tasks like addressing, routing, and transport. (Figure 1.5)



Internet	Application layer Transport layer Internet layer
Wireless data communications	Link (MAC) layer
2.4 GHz ISM band radio interface	Physical layer

Figure 1.5: The Wi-Fi Protocol Stack.

1.3.2.4. Wi-Fi Access Point (AP):

A Wi-Fi access point serves as the central hub for connecting wireless devices to a wired network or the internet. It provides wireless coverage, manages client connections, and forwards data packets between wireless devices and the wired infrastructure.

Wi-Fi access points integrate PHY and MAC functionality along with additional features like network authentication, encryption, and traffic management. They serve as the interface between wireless devices and the rest of the network, enabling seamless communication and connectivity. [17]

1.3.3. Routing:

Routing is a fundamental concept in computer networking that involves the process of determining the optimal path for data packets to travel from a source to a destination across a network. It plays a crucial role in facilitating communication between devices within a network by directing data packets along the most efficient paths. [18]

1.3.3.1. Routing Strategies:

There are two strategies:

a) Static Routing: Static routing involves manually configuring routing tables on network devices. While simple to implement, static routing lacks adaptability and scalability, making it suitable only for small, stable network environments.

b) Dynamic Routing: Dynamic routing protocols enable routers to exchange routing information and dynamically adjust routing tables based on network changes. Examples include RIP, OSPF, and BGP. Dynamic routing offers flexibility and scalability, making it ideal for large and dynamic networks. [18]

1.3.3.2. Routing Algorithms:

Routing algorithms are the computational procedures used by routers in computer networks to determine the optimal paths for data packets to travel from a source to a destination. These algorithms play a crucial role in ensuring efficient and reliable communication by selecting the most appropriate routes based on various factors such as network topology, link costs, and routing metrics. There are several types of routing algorithms, each with its own characteristics and suitability for different network environments. Some common routing algorithms include:

a) Shortest Path Algorithms: Algorithms like Dijkstra's algorithm calculate the shortest path between a source and destination based on metrics such as hop count or link cost.

b) Distance Vector Algorithms: Routing Information Protocol (RIP) is an example of a distance vector algorithm that calculates routes based on distance vectors exchanged between routers.

c) Link State Algorithms: Open Shortest Path First (OSPF) is a link state algorithm that maintains a detailed map of the network topology to calculate routes. [19]

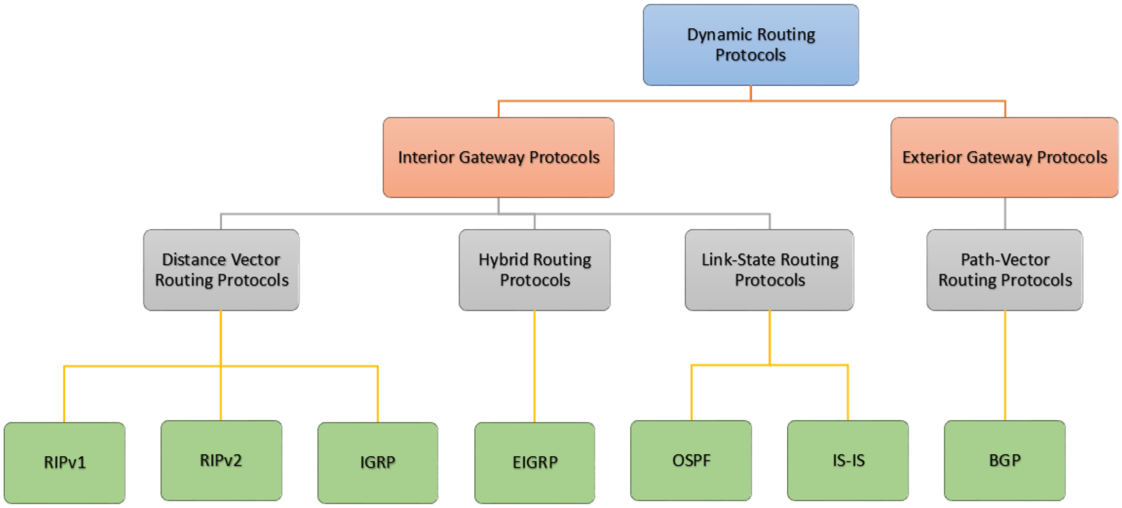


Figure 1.6: Dynamic Routing protocols.

1.3.4. Digital Data Transmission Techniques:

Digital data transmission techniques refer to the methods and protocols used to convey digital information reliably and efficiently from one point to another in communication systems. These techniques are fundamental in various domains such as telecommunications, computer networks, and wireless communication. Some commonly employed digital data transmission techniques include:

a) Modulation techniques: Modulation alters a carrier signal's properties to encode digital data. Binary Phase Shift Keying (BPSK), Quadrature Amplitude Modulation (QAM), and Frequency Shift Keying (FSK) are examples.

b) Error Detection and Correction: Techniques like Cyclic Redundancy Check (CRC) and Forward Error Correction (FEC) detect and correct errors in transmitted data, ensuring data integrity.

c) Multiplexing Techniques: Multiplexing allows multiple signals to share a common transmission medium. Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM) are commonly used.

d) Packet Switching: Data is divided into packets, each contain routing information. Transmission Control Protocol/Internet Protocol (TCP/IP) and User Datagram Protocol (UDP) are examples of packet-switched protocols.

e) Compression Techniques: Compression reduces the size of transmitted data. Lossless compression (e.g., ZIP) and loss compression (e.g., JPEG) are used to optimize bandwidth usage.

f) Encryption and Cryptography: Encryption algorithms like Advanced Encryption Standard (AES) and protocols like Secure Sockets Layer/Transport Layer Security (SSL/TLS) ensure data security during transmission.

g) Channel Access Protocols: These protocols govern how devices access a shared transmission medium. Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) are examples. [20]

1.4. WiMAX:

WiMAX (Worldwide Interoperability for Microwave Access) is a connection-oriented wide area network. It supports high bandwidth and hundreds of users per channel at speeds similar to currently seen for DSL, Cable or a T1 connection; Promises to provide a range of 30 miles as an alternative to wired broadband like cable and DSL. It could potentially provide broadband access to remote places. Use point-to-multipoint (P2MP) architecture. It is designed for delivering broadband seamless quality multimedia services to the end users. "WiMAX combines the familiarity of Wi-Fi with the mobility of cellular that will deliver personal mobile broadband that moves with you". [21]

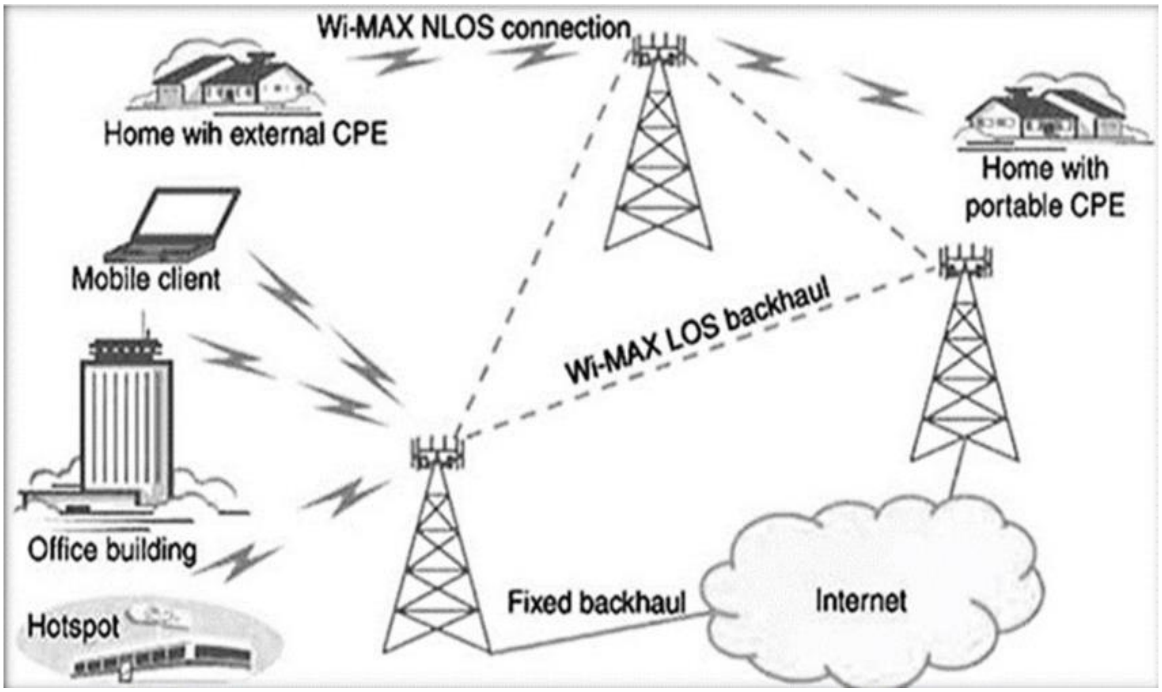


Figure 1.7: Illustration of WiMAX Network Architecture.

1.4.1. Evolution of WiMAX:

The evolution of WiMAX (Worldwide Interoperability for Microwave Access) technology has progressed through several iterations, each introducing enhancements and improvements.

Here's an overview of the key stages in the evolution of WiMAX:

a) IEEE 802.16 Working Group: In 1988, IEEE 802.16 working group developed WMAN solution for LOS (Line of Sight) based point to point and point to multi point wireless broadband systems. Frequency range of IEEE 802.16 is 10 GHz to 66 GHz.

b) IEEE 802.16a: IEEE 802.16a standard was produced in January 2003. It has frequency range of 2 GHz to 11 GHz and provides NLOS (Non-Line of Sight) communication.

c) IEEE 802.16-2004: This standard supports for fixed applications so it is called as Fixed WiMAX or IEEE 802.16d. It supports OFDM (Orthogonal Frequency Division Multiplexing) in physical layer. It is also known as Fixed WiMAX.

d) IEEE 802.16e-2005: IEEE 802.16e-2005 was launched in December 2005. It provides support for nomadic and mobility services so it also known as Mobile WiMAX. It supports SOFDMA (Scalable Orthogonal Frequency Division Multiple Access) in physical layer of WiMAX. [21]

Overall, the evolution of WiMAX from its initial fixed wireless focus to its later mobile broadband capabilities reflects the ongoing efforts to improve wireless connectivity and meet the evolving demands of consumers and businesses for high-speed internet access.

1.4.2. Advantages of WiMAX:

WiMAX technology offers several advantages:

a) Broad Coverage: WiMAX technology can cover large geographical areas, providing connectivity to remote or underserved regions where traditional wired infrastructure is impractical or unavailable.

b) High-speed Internet Access: WiMAX offers high-speed broadband access, enabling users to enjoy fast internet connections for various applications such as streaming, gaming, and downloading large files.

c) Flexibility and Mobility: With WiMAX, users can access the internet on the go. Mobile WiMAX standards (such as IEEE 802.16e) allow for seamless connectivity while moving, similar to cellular networks, making it suitable for portable devices like smartphones, tablets, and laptops.

d) Scalability: WiMAX networks are easily scalable, allowing service providers to expand coverage and capacity as demand increases without the need for extensive infrastructure upgrades.

e) Cost-Effective Deployment: Deploying WiMAX networks can be more cost-effective compared to laying cables for traditional wired networks, especially in rural or remote areas where terrain or population density makes wired infrastructure expensive.

f) Versatility: WiMAX technology can be deployed for various applications including residential broadband, enterprise connectivity, backhaul for cellular networks, and public Wi-Fi hotspots, providing a versatile solution for different deployment scenarios. [22]

These advantages collectively position WiMAX as a viable option for delivering high-speed broadband access over long distances, addressing the needs of users and service providers in diverse environments.

CHAPTER 2

FUNDAMENTALS OF ANTENNAS

2.1. An Antenna:

An antenna is a device designed to transmit or receive electromagnetic waves. It is typically constructed to effectively radiate or capture radio frequency (RF) energy, enabling communication between electronic devices or systems over a distance without the need for physical connections. Antennas are used in various applications, including wireless communication systems, radio and television broadcasting, radar systems, and more. [23]

2.1.1. Evolution and presentation of Antenna:

The history of antennas dates back to the late 19th century, coinciding with the pioneering work of scientists such as James Clerk Maxwell and Heinrich Hertz in understand the nature of electromagnetic waves. [24]

Here's a brief overview of the history of antennas:

2.1.1.1. Maxwell's Equations:

James Clerk Maxwell formulated the equations describing the behavior of electromagnetic fields. His equations provided a theoretical framework for understanding the propagation of electromagnetic waves, laying the foundation for the development of antennas.

The Maxwell's equations relevant to antennas include:

- Gauss's Law for Electricity: $\nabla \cdot E = \frac{\rho}{\varepsilon_0}$
- Gauss's Law for Magnetism: $\nabla \cdot B = 0$
- Faraday's Law of Electromagnetic Induction: $\nabla \times \mathrm{E} = -\frac{\partial B}{\partial t}$
- Ampère's Law with Maxwell's Addition: $\nabla \times \mathrm{B} = \mu_0 \left(j + \varepsilon_0 \frac{\partial E}{\partial t} \right)$

(E) is the electric field vector,

(B) is the magnetic field vector,

(ρ) is the charge density,

(J) is the current density,

(ε0) is the vacuum permittivity (electric constant),

(μ0) is the vacuum permeability (magnetic constant),

(∇·) represents the divergence operator, and

(∇×) represents the curl operator.

These equations govern the behavior of electric and magnetic fields, their interactions with charges and currents (represented by ρ and J respectively), and the propagation of electromagnetic waves. Antennas operate by manipulating electromagnetic fields in accordance with these fundamental principles. [24]

2.1.1.2. Hertz's Experiments:

Heinrich Hertz conducted experiments to demonstrate the existence of electromagnetic waves predicted by Maxwell's equations. His experiments with spark gap transmitters and receivers led to the first practical demonstrations of wireless communication.

Hertz used an apparatus consisting of a high-voltage induction coil connected to a pair of electrodes with a small gap between them. When a high voltage was applied across the electrodes, it caused a spark to jump across the gap, creating a rapidly changing electric field. [24]

As shown in Figure.2.1.

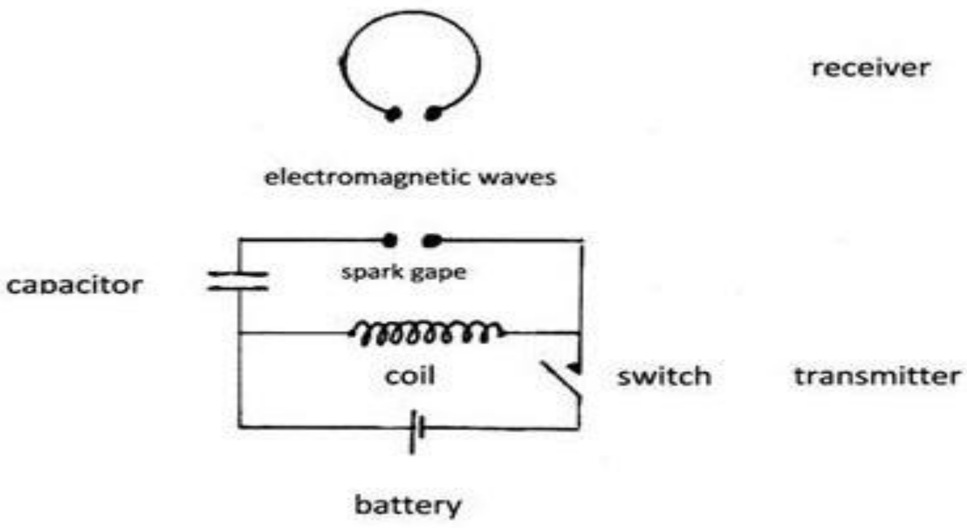


Figure 2.1: Generation of Electromagnetic Waves Experiment.

2.1.1.3. Early Antenna Designs:

In the early 20th century, engineers and scientists began experimenting with various antenna designs to improve the efficiency and performance of wireless communication systems. This era saw the development of simple wire antennas, such as the dipole and monopole antennas shown in figure 2.2.

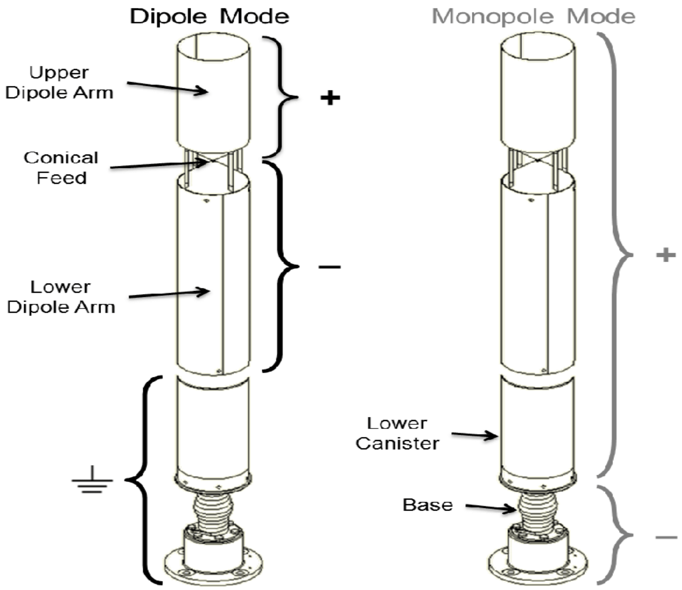


Figure 2.2: Dipole and Monopole modes.

Antennas played a pivotal role in the development of radar systems during World War II, enabling the detection and tracking of aircraft and ships. Radar systems introduced innovations such as directional antennas, phased arrays, and reflector antennas to achieve long-range detection and improved accuracy.

The rise of broadcasting and television in the mid-20th century drove further advancements in antenna technology. Antennas for TV reception evolved from simple dipole and Yagi-Uda designs to more sophisticated phased arrays and parabolic reflectors for improved signal reception and directionality. [24]

2.1.1.4. Wireless Communication Innovation:

The advent of cellular networks, Wi-Fi, Bluetooth, and other wireless communication technologies spurred continuous innovation in antenna design.

Antennas became smaller, more efficient, and capable of operating across multiple frequency bands to support diverse communication needs.

Antennas continue to evolve to meet the demands of emerging technologies such as 5G, IoT, and beyond. Advanced antenna technologies like massive MIMO, beam forming, and reconfigurable antennas are driving the next wave of wireless communication innovation. [25]

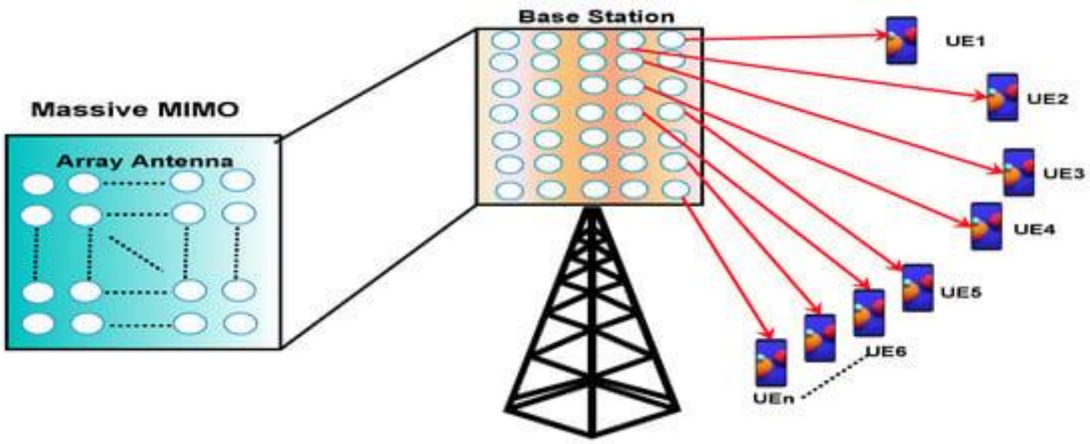


Figure 2.3: Representation of multi-input and multi-output (MIMO).

2.2. Main Parameters and Characteristics:

An antenna is a crucial component in telecommunications systems, allowing the transmission and reception of electromagnetic waves. Various parameters and characteristics define its performance. [24]

2.2.1. Resonance Frequency:

The resonance frequency of an antenna refers to the frequency at which the antenna exhibits the highest efficiency and most effective radiation characteristics. At resonance, the antenna's reactance cancels out, leaving only its resistance component. This results in maximum power transfer between the antenna and the transmission line or source.

The resonance frequency of an antenna depends on its physical dimensions, geometry, and the dielectric properties of its surroundings. For common antenna types, such as dipoles or monopoles, the resonance frequency can be calculated using empirical formulas or numerical simulations. However, it's important to note that the resonance frequency may vary depending on factors such as nearby objects, materials, and environmental conditions.

For a simple dipole antenna, the resonance frequency (f) can be approximated using the formula: $f = \frac{\mathrm{c}}{2L}$ where:

- F is the resonance frequency (in Hertz).
- C is the speed of light in a vacuum (approximately 3×10^8 meters per second).
- L is the effective length of the antenna (in meters).

For a half-wavelength dipole, the effective length is half the wavelength (λ/2). Therefore, the formula simplifies to: $f = \frac{\mathrm{c}}{\lambda}$

Where: λ is the wavelength of the electromagnetic wave and is given by: λ= c / f [26]

2.2.2. Bandwidth:

The bandwidth of an antenna can be characterized in various ways depending on the specific performance parameters being considered. One common method to define bandwidth is based on the impedance matching characteristics of the antenna, known as impedance bandwidth. Another method is based on the radiation characteristics of the antenna, known as radiation bandwidth or operational bandwidth. [26]

2.2.3. Impedance Bandwidth:

Impedance bandwidth is typically defined in terms of the range of frequencies over which the antenna's impedance matches the impedance of the transmission line or system to which it is connected within a certain tolerance. It is often specified as the frequency range over which the antenna's return loss is below a certain threshold, such as -10 dB or -20 dB.

The equation for calculating impedance bandwidth is not straightforward and often involves empirical or measurement-based methods. However, it is commonly expressed as a percentage of the center frequency:

$$Impedance\ bandwith(\%) = \frac{f_{upper} - f_{lower}}{f_{center}} \times 100\%$$

- f_{lower} and f_{upper} are the lower and upper frequency limits of the impedance bandwidth, respectively.
- f_{center} is the center frequency of the impedance bandwidth. [26]

And there is Radiation Bandwidth.

2.2.4. Radiation Bandwidth:

Radiation bandwidth is defined in terms of the frequency range over which the antenna maintains desired radiation characteristics, such as gain, radiation pattern, and efficiency, within specified limits. It is often expressed as the range of frequencies over which the antenna's gain remains within a certain percentage of its peak gain. [26]

2.2.5. Return Losses:

Return loss is a measure of the amount of power reflected back towards the source due to impedance mismatches along the transmission line and at the antenna terminals. It's usually expressed in decibels (dB) and is an essential parameter in assessing the efficiency and effectiveness of an antenna system.

The return loss (RL) can be calculated using the following equation:

$$\mathrm{RL} = 10\log_{10}\frac{P_{in}}{P_{refl}}$$

- RL is the return loss (in dB).
- P_{in} is the power incident on the antenna (forward power).
- P_{refl} is the power reflected back towards the source.

Return loss can also be related to the Voltage Standing Wave Ratio (VSWR) using the following equation:

$$\mathrm{RL} = -20\log_{10}\left(\frac{VSWR+1}{VSWR-1}\right)$$

Where: VSWR is the ratio of the maximum voltage to the minimum voltage on the transmission line.

Low return loss indicates a well-matched system with minimal power being reflected back to the source, while high return loss suggests poor impedance matching and significant power loss due to reflection.

In antenna design and testing, achieving low return loss is essential to maximize power transfer efficiency and ensure optimal performance of the antenna system. [26]

2.2.6. Gain:

The gain of an antenna is a measure of its ability to direct or focus radiation in a particular direction compared to an ideal isotropic radiator (which radiates equally in all directions). Gain is typically expressed in decibels (dB) and is an essential parameter in antenna design and performance evaluation. Higher gain implies a more focused radiation pattern and increased signal strength in the desired direction.

The gain (G) of an antenna is calculated using the following equation:

$$\mathrm{G} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- G is the gain of the antenna (in decibels, dB).
- P_{out} is the power radiated in the direction of interest by the antenna (in watts).
- P_{in} is the power that an ideal isotropic radiator would emit in the same direction if it had the same input power as the actual antenna (in watts).

Antennas with higher gain concentrate more energy in specific directions, resulting in increased signal strength and coverage in those directions. However, higher gain antennas may have narrower beam widths, limiting their coverage area. The choice of antenna gain depends on the specific requirements of the application, such as coverage area, range, and directionality.

It's important to note that while gain is a crucial parameter, it doesn't represent an increase in the total radiated power of the antenna system. Instead, it describes the concentration of radiated power in a particular direction compared to a reference antenna. [26]

2.2.7. Characteristic Impedance:

Any media that can support an electromagnetic wave has characteristic impedance associated with it. Although characteristic impedance units are in Ohms, it is not real impedance you can measure using direct current equipment such as a DC Ohmmeter. And although transmission lines have real loss at microwave frequencies, this isn't what we're talking about either.

The best way to think about characteristic impedance, it envision an infinitely long transmission line, which means that there will be no reflections from the load. Placing an alternating current voltage $V_{in}(t)$ will result in a current $I_{in}(t)$. The impedance of the transmission line is then:

$$Z_0 = \frac{V_{in}}{I_{in}}$$

Sounds simple enough, but unless you are dealing with "free space", there is no transmission line that is infinitely long. But that equation is starting to look like a version of Ohm's law, where R=V/I.

The general expression that defines characteristic impedance is:

$$Z_0 = \sqrt{\frac{Z\prime}{Y\prime}} \quad ; \quad Z_0 = \sqrt{\frac{R\prime + j\omega L\prime}{G\prime + j\omega C\prime}}$$

Here R', G', L' and C' are normalized to length.

For a low-loss transmission line, the following relationships will occur:

$$G' \ll j\omega C' \quad ; \quad R' \ll j\omega L'$$

Then for all practical purposes we can ignore the contributions of R' and G' from the equation and end up with a nice scalar quantity for characteristic impedance.

And the more familiar equation for characteristic impedance is simply:

$Z_0 = \frac{L\prime}{C\prime}\ (ohms)$, L' is the tendency of a transmission line to oppose a change in current, while C' is the tendency of a transmission line to oppose a change in voltage. Characteristic impedance is a measure of the balance between the two. [27]

2.2.8. Radiation Patterns:

The radiation pattern (RP) (or antenna pattern) is the representation of a radiation property of the antenna as a function of the angular coordinates.

The trace of the angular variation of the received/radiated power at a constant radius from the antenna is called the power pattern. The trace of the angular variation of the magnitude of the electric (or magnetic) field at a constant radius from the antenna is called the amplitude field pattern.

RP is measured in the far-field region, where the angular distribution of the radiated power does not depend on the distance. We measure and plot either the field intensity, $E(\theta,\varphi)$, or the power $E(\theta,\varphi)^2/\eta = \eta H(\theta,\varphi)^2$.

Usually, the pattern describes the normalized field (or power) values with respect to the maximum value.

The pattern can be a 3D plot (both θ and φ vary), or a 2D plot. A 2D plot is obtained as an intersection of the 3D RP with a given plane, usually a θ = const. plane or a φ = const. plane that must contain the pattern's maximum.

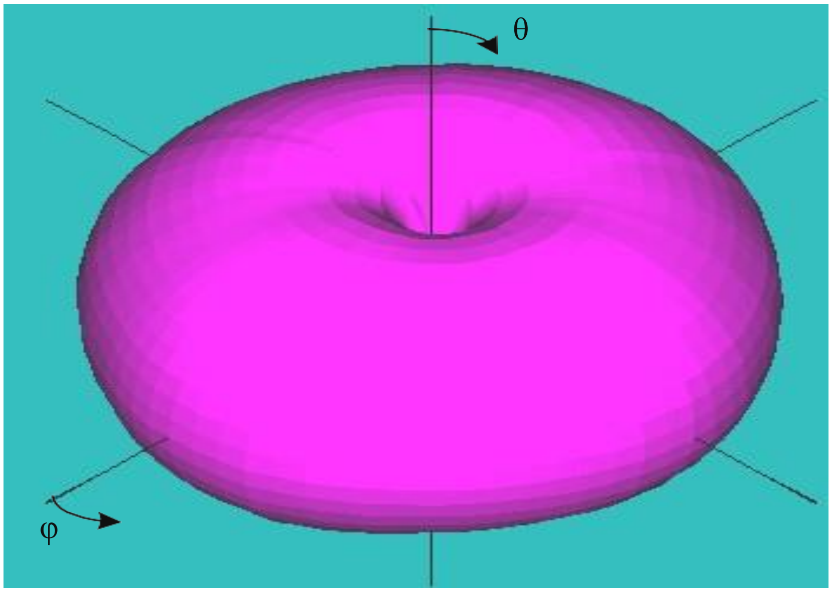


Figure 2.4: 3D Pattern of a Dipole.

There are several types of radiation patterns exhibited by antennas, each with its own characteristics and applications. Some of the common types include:

a) Isotropic Pattern: Isotropic Pattern is the pattern of an antenna having equal radiation in all directions. This is an ideal concept, which, strictly speaking, is achievable only approximately in a narrow frequency band. However, it is used to define other antenna parameters. It is represented simply by a sphere whose center coincides with the location of the isotropic radiator.

b) Omnidirectional Radiation Pattern: Radiation is uniform in one plane but can vary in the orthogonal plane. Antennas with omnidirectional patterns radiate or receive signals equally in all directions around a central axis, commonly used in applications requiring coverage in all directions, such as mobile communication base stations, Wi-Fi routers, and broadcast antennas.

The pattern in the figure 2.5 below is that of a dipole – it is omnidirectional.

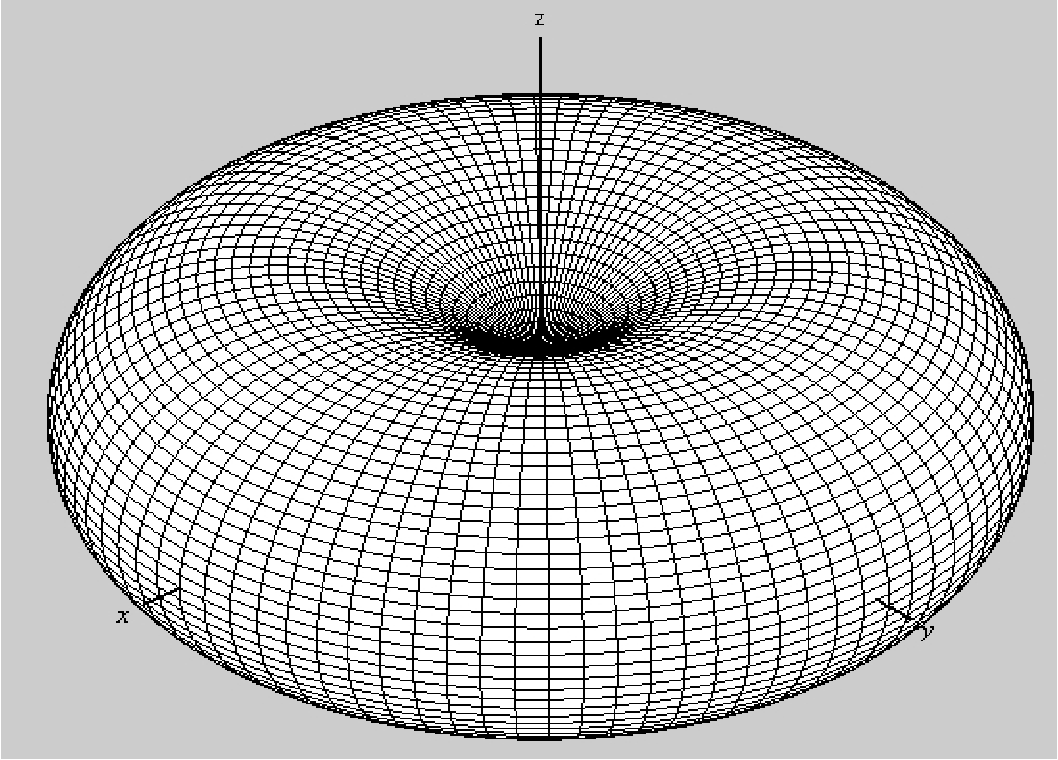


Figure 2.5: Omnidirectional 3D Pattern.

c) Directional Radiation Pattern: Directional Radiation Pattern is concentrated radiation in specific directions. Used in point-to-point communication links, radar systems, and satellite communication for targeting specific areas or objects. This type of pattern is based on the degree of directionality: Highly Directional concentrates energy into a narrow beam. Moderately Directional offers a compromise between omnidirectional and highly directional patterns. Sectorial covers specific sectors or angles.

d) Pattern Lobe: Pattern lobe is a portion of the RP with a local radiation-intensity maximum and limits defined by neighboring nulls. Lobes are classified as: major, minor, side lobes, back lobes, as Figure 2.6 shows.

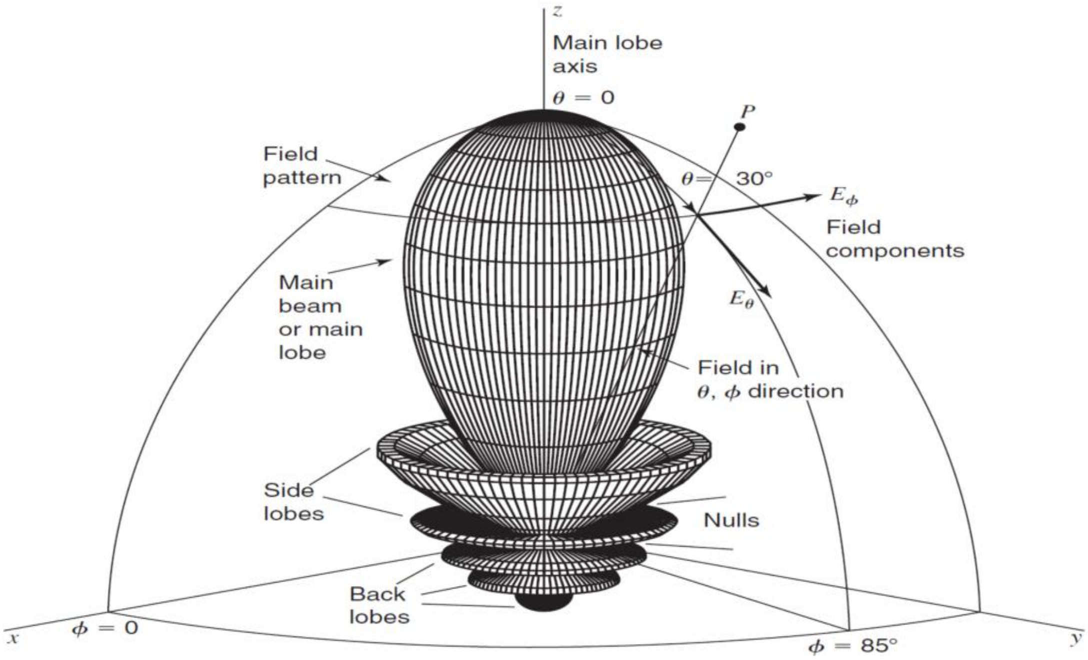


Figure 2.6: Pattern Lobe.

e) Principal Radiation Patterns: The principal radiation pattern of an antenna refers to the primary or dominant pattern of radiation that characterizes its directional behavior. It is essentially the main lobe of the radiation pattern, representing the region in which the majority of the radiated energy is concentrated.

2D patterns can be polar or rectangular, depending on the way the angle is depicted, and linear or logarithmic (in dB), depending on the chosen pattern scale. The plots below show the same 2D pattern in 4 different formats. [24]

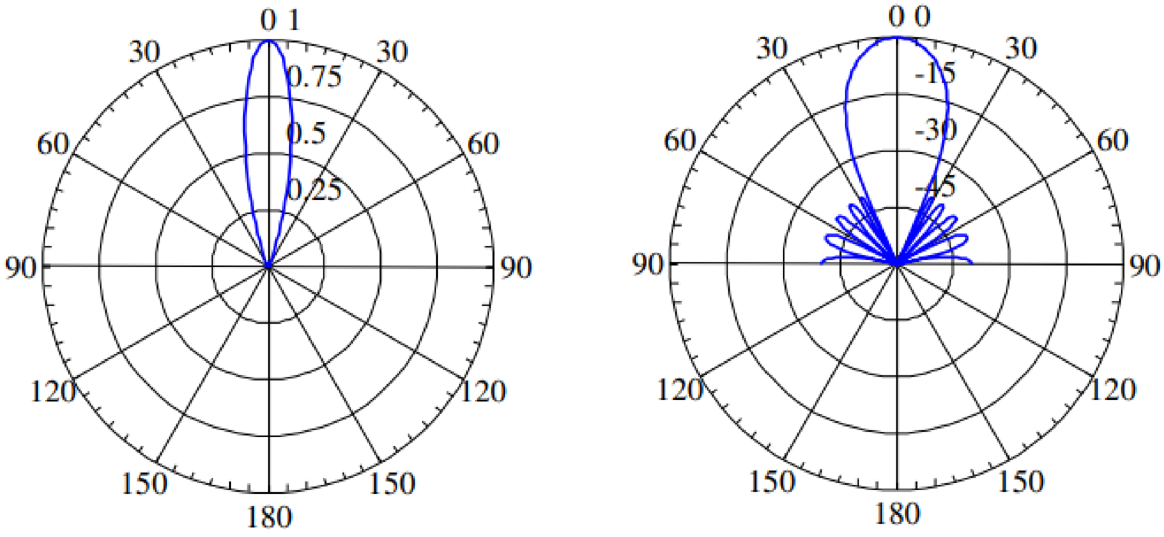


Figure 2.7: Polar Pattern (linear scale) & Polar Pattern (dB scale).

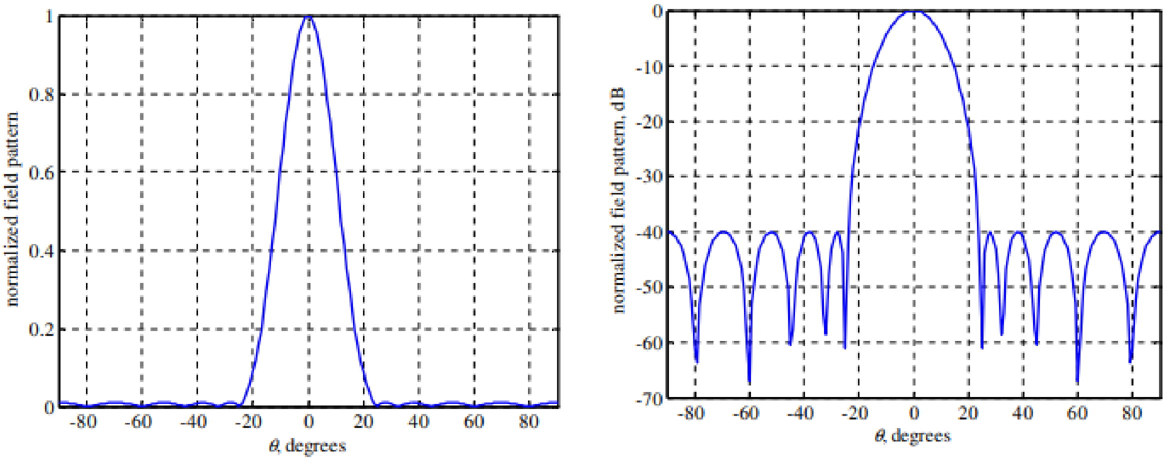


Figure 2.8: Rectangular Pattern (linear scale) & Rectangular Pattern (dB).

2.3. Types of Antenna:

The antenna serves to a communication system the same purpose that eyes and eyeglasses serve to a human. The field of antennas is vigorous and dynamic, and over the last 60 years antenna technology has been an indispensable partner of the communications revolution. Many major advances that occurred during this period are in common use today; however, many more issues and challenges are facing us today, especially since the demands for system performances are even greater. [24]

We will introduce and discuss some forms of the various antenna types.

2.3.1. Wire Antenna:

Wire antennas are commonly recognized by the general public due to their ubiquitous presence on automobiles, buildings, ships, aircraft, and spacecraft. Figure 2.9 illustrates different shapes of wire antennas, including straight wires (dipoles), loops, and helices. Loop antennas, while often circular, can also take on other shapes such as rectangles, squares, or ellipses. Among these, the circular loop is most prevalent owing to its simple construction. [24]

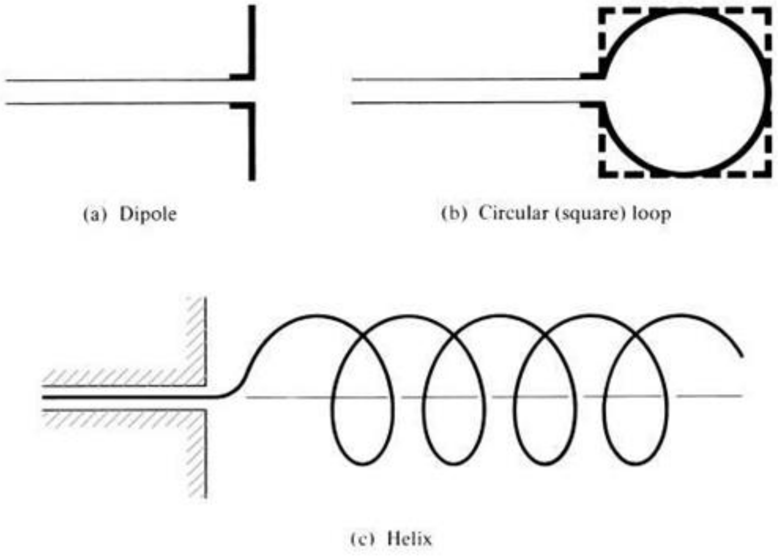


Figure 2.9: Wire Antenna Configurations.

2.3.2. Aperture Antenna:

The increasing demand for sophisticated antennas and higher frequencies has made aperture antennas more familiar to the general public today compared to earlier times. Figure 2.10 depicts various forms of these antennas. They are particularly valuable for aircraft and spacecraft applications due to their ability to be flush-mounted onto the vehicle's skin. Additionally, they can be safeguarded from environmental hazards by covering them with a dielectric material. [24]

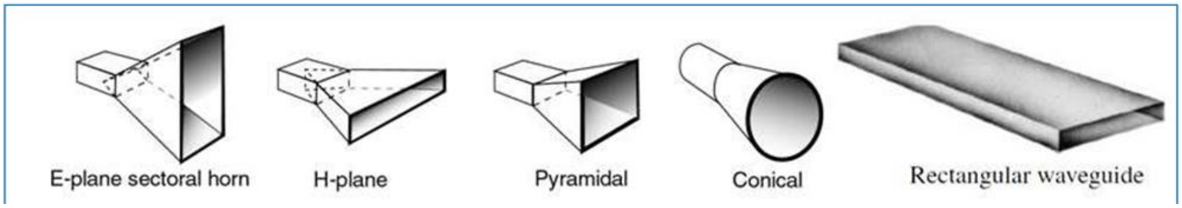
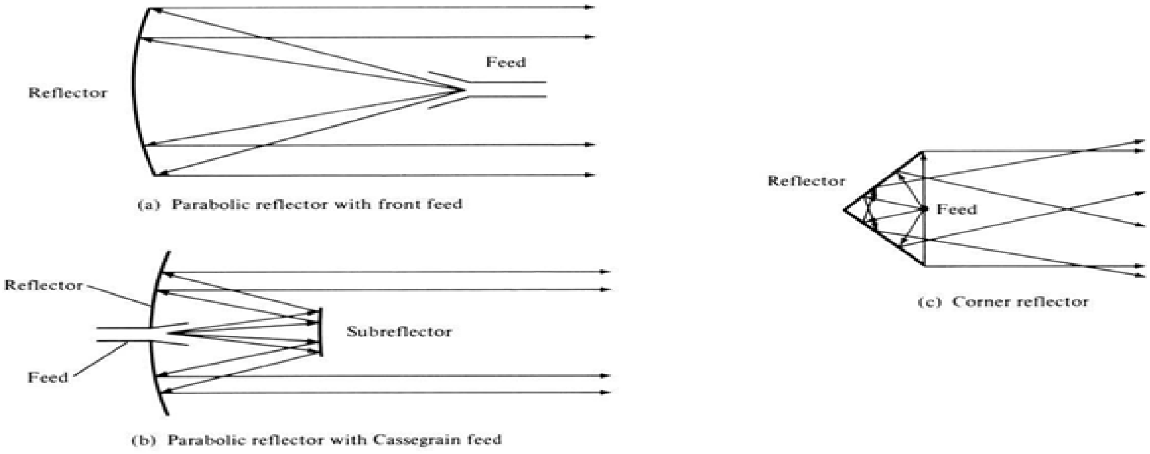


Figure 2.10: Aperture Antenna Configurations.

2.3.3. Reflector Antenna:

The progress made in outer space exploration has driven advancements in antenna theory. To facilitate communication over vast distances, sophisticated antenna designs became necessary to transmit and receive signals spanning millions of miles. One prevalent form of antenna for such applications is the parabolic reflector, as depicted in Figures 2.11(a) and (b). These antennas have been constructed with diameters reaching up to 305 meters, essential for achieving the high gain required to handle signals traversing such extensive distances. Another type of reflector though less common than the parabolic is the corner reflector. Illustrated in Figure 2.11 (c). [24]



(a) Parabolic reflector with front feed

(b) Parabolic reflector with Cassegrain feed

(c) Corner reflector

Figure 2.11: Typical Reflector Configurations.

2.3.4. Microstrip Antenna:

Microstrip antennas gained significant popularity in the 1970s, initially for space-borne applications, and today they are extensively utilized in both government and commercial sectors. These antennas are composed of a metallic patch situated on a grounded substrate. The metallic patch can assume various configurations, as illustrated in Figure 2.12 below. [24]

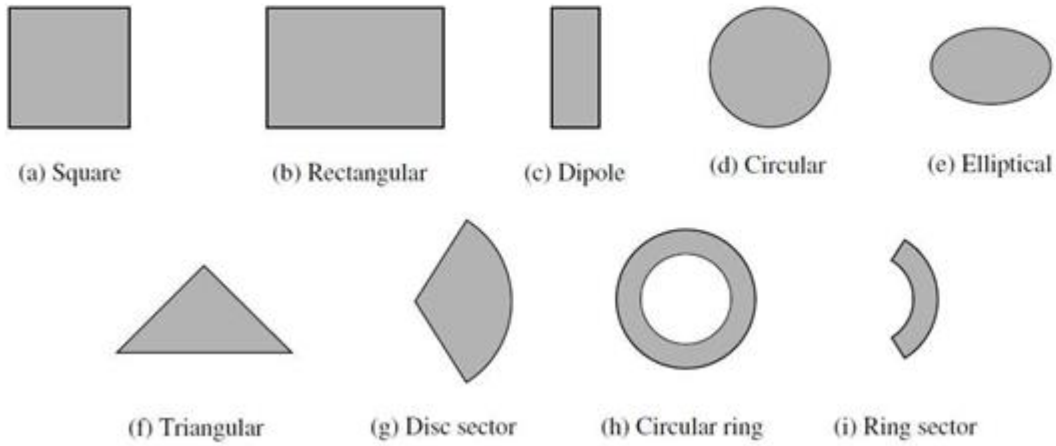


Figure 2.12: Representative Shapes of Microstrip Patch Elements.

The rectangular and circular patches, shown in Figure 2.13, are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.

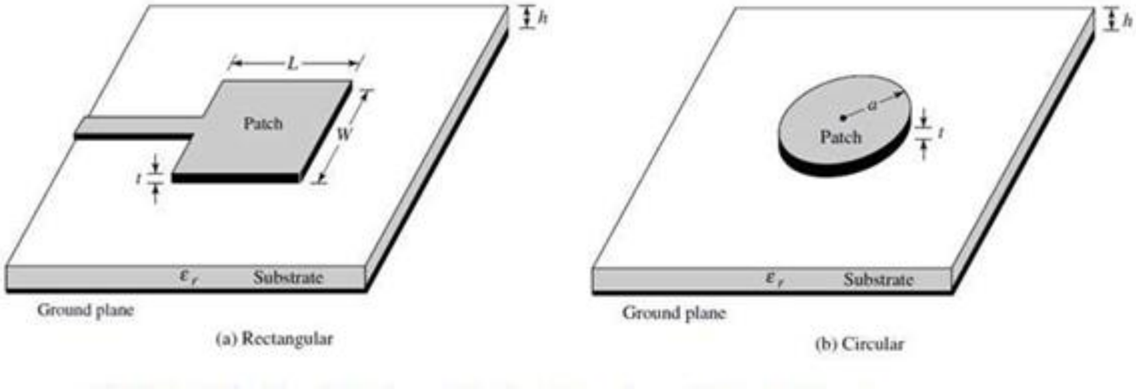
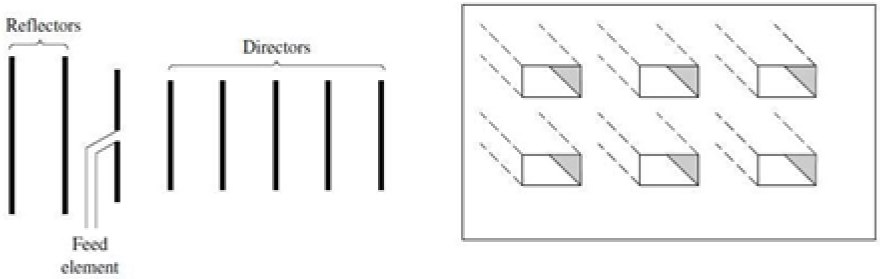


Figure 2.13: Rectangular and circular Microstrip (Patch) Antennas.

2.3.5. Array Antenna:

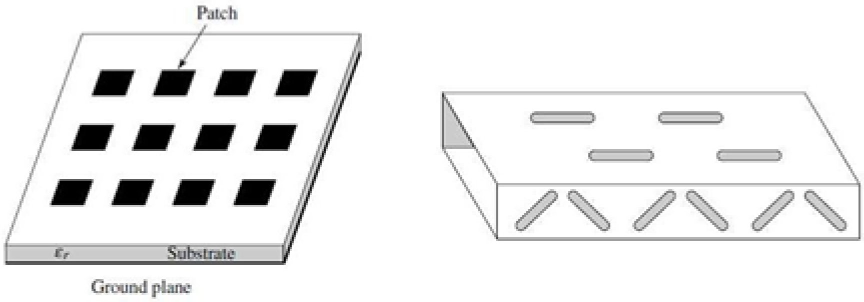
In numerous applications, achieving desired radiation characteristics may not be feasible with a single element alone. However, it is often possible to attain the desired radiation characteristics by arranging a group of radiating elements in both electrical and geometrical configurations, forming what is known as an array. The arrangement of the array can be designed such that the radiation emitted by the individual elements combines to produce a maximum radiation in specific directions, while minimizing radiation in others, or achieving other desired radiation patterns as needed. [24]

Examples of typical arrays are depicted in Figure 2.14. Traditionally, the term "array" denotes a configuration where the individual radiators are separate and distinct, as shown in Figures 2.14(a–c). However, the same term is also applied to describe an assembly of radiators mounted on a continuous structure, as illustrated in Figure 2.14(d).



(a) Yagi-Uda array

(b) Aperture array



(c) Microstrip patch array

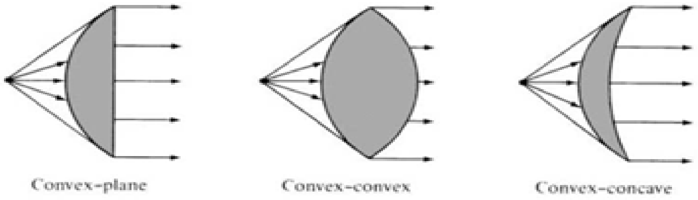
(d) Slotted-waveguide array

Figure 2.14: Typical Wire, Aperture and Microstrip array configurations.

2.3.6. Lens Antenna:

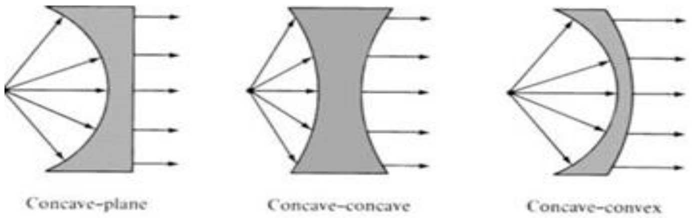
Lenses serve the primary function of collimating incident divergent energy to prevent it from dispersing in undesired directions. Through careful shaping of their geometrical configuration and selection of appropriate materials, lenses have the capability to convert various forms of divergent energy into plane waves. They find applications similar to those of parabolic reflectors, particularly at higher frequencies. However, their dimensions and weight become impractically large at lower frequencies. Lens antennas are categorized based on the material they are made of or their geometrical shape. [24]

Various forms of lens antennas are depicted in Figure 2.15 and 2.16.



Convex-plane Convex-convex Convex-concave

Figure 2.15: Lens with Index of n<1.



Concave-plane Concave-concave Concave-convex

Figure 2.16: Lens with Index of n>1.

In summary, an ideal antenna is one that will radiate all the power delivered to it from the transmitter in a desired direction or directions. In practice, however, such ideal performances cannot be achieved but may be closely approached. Various types of antennas are available and each type can take different forms in order to achieve the desired radiation characteristics for the particular application.

CHAPTER 3

PLANAR ANTENNAS

3.1. Planar Technology:

During the past several decades, much attention has been focused on the development of planar antennas. These antennas are highly desirable for a number of reasons. First, they can be manufactured at a much lower cost than waveguide-based antenna technology and are considerably more compact and lightweight. These characteristics are essential for the many commercial applications that planar antennas are increasingly used in, such as base station or handset antennas. Second, the planar nature of the antennas makes them ideal for large arrays and simplifies the interaction of additional electronics, such as amplifiers and phase shifters, which are essential for electronic warfare, radar, satellite communications or millimeter-wave imaging. Their planar nature also allows the antennas to be used in applications where size and shape are crucial, such as conformal printed antennas on an airplane fuselage. This myriad of applications has led to the development of a wide variety of planar antenna classes. [28]

3.1.1. Advances of Planar Technology:

Planar antenna technology has seen significant advances in recent years, offering numerous benefits such as reduced size, weight, and cost, making them suitable for various applications including satellite communication, wireless communication systems, radar systems, and more.

Some of the key advances in planar antenna technology include:

a) Multiband and Wideband Operation: Planar antennas have been developed to operate across multiple frequency bands or with wideband characteristics. This advancement is crucial for modern communication systems where versatility and flexibility are required. Techniques such as impedance matching, bandwidth enhancement, and radiating element optimization have contributed to achieving multiband and wideband performance.

b) Miniaturization and Low Profile Design: Advances in planar antenna design have led to miniaturization and low-profile antennas, which are essential for applications where size and form factor constraints exist, such as in mobile devices, IoT sensors, and wearable electronics. Techniques like metamaterials-based structures, fractal geometries, and stacked patch configurations have enabled the development of compact planar antennas while maintaining acceptable performance.

c) Integration with RF Front-Ends and System-on-Chip (SoC): Planar antennas are increasingly being integrated with RF front-end modules and SoC solutions, leading to highly integrated wireless systems with reduced complexity, size, and cost. Integration facilitates better impedance matching, reduced signal losses, and improved overall system performance.

d) Reconfigurable and Adaptive Antennas: Planar antennas with reconfigurable and adaptive features have been developed to dynamically adjust their operating parameters such as frequency, radiation pattern, and polarization. This capability enables adaptive beam forming, interference mitigation, and improved signal reception, making these antennas suitable for dynamic and changing wireless environments.

e) Metamaterials and Metasurfaces: The integration of metamaterials and metasurfaces with planar antenna structures has enabled the realization of unconventional electromagnetic properties and functionalities. Metamaterials-based planar antennas offer advantages such as enhanced gain, improved bandwidth, and control over radiation characteristics, opening up new possibilities for advanced antenna designs. [28]

3.1.2. Limitations of Planar Technology:

Planar antennas while popular and widely used due to their low profile and ease of integration into electronic devices have some limitations. Here are a few:

a) Bandwidth Constraint: Planar antennas often exhibit limited bandwidth compared to other types of antennas such as wire antennas or aperture antennas. This limitation arises due to the compact size and planar structure, which restricts the range of frequencies over which the antenna can efficiently radiate or receive electromagnetic signals.

b) Radiation Efficiency: Planar antennas may suffer from lower radiation efficiency, particularly at lower frequencies. This inefficiency is often attributed to the presence of losses in the antenna structure, including conductor losses, dielectric losses, and surface wave losses.

c) Environmental Sensitivity: Planar antennas may exhibit sensitivity to variations in the surrounding environment, including changes in nearby objects, ground planes, and environmental conditions such as humidity and temperature. These environmental factors can influence antenna performance and introduce variations in radiation patterns and impedance matching.

d) Surface Wave Excitation: Planar antennas can be prone to surface wave excitation, especially when operating in close proximity to a conducting surface or a dielectric substrate. Surface waves can lead to unwanted radiation patterns, spurious emissions, and degradation in antenna performance.

e) Polarization Diversity: Planar antennas may have limitations in achieving polarization diversity, which is crucial in certain communication systems for mitigating polarization fading and improving link reliability.

f) Gain Limitation: Planar antennas generally exhibit lower gain compared to three-dimensional antennas. While this might not be a significant issue for many applications, it can be a limitation in scenarios where long-range communication or high gain is required. [29]

3.2. Printed Antennas:

Wireless communication is the latest emerging pillar in the field of communication. It has reshaped the way of communication and connectivity. Its various applications such as broadcast of information, personal communication, satellite communication and mobile communication have notable merits such as simplicity in design, light weight, easy execution and estimate. The progress in wireless local area networks (WLANs), cell phone networks, satellite communication and other different wireless networks shows the demand as well as interest in the distinctive area of information technology and communication. Due to the blooming of advanced communication applications, there is a high demand of highly advanced and smart antennas, which are regarded as the key for wireless technologies. For wireless technology, the antenna with multiband operating property having high performance and features such as easy to control, easily manufactured, light weight, and simple structure etc. are preferred. Its two most interesting features are: physical simplification and flat structure, which lead the printed antennas to be the common choice of designers to assemble a printed antenna. Due to its engineering process, the simplest form of printed antenna is micro-strip antenna. Now-a-days electronic circuits not only used for a transmission line but also components such as filters, couplers, resonators, etc. frequently use an open-wave guiding structure known as micro-strip.

The use of micro-strip for constructing antennas is a new development, and an example of a micro-strip antenna is shown in Figure 3.1. The conducting ground plane supports the complete lower portion of the dielectric substrate, whereas the printed conducting strip is placed at the upper portion of the dielectric substrate. [30]

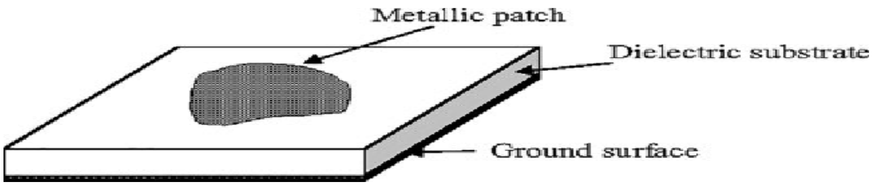


Figure 3.1: Basic Configuration of a Printed Antenna.

3.2.1. Feeding Methods of Printed Antennas:

There are several kinds of methods to feed a printed antenna and are explained in this section. To choose an appropriate feeding method for the design of a particular type of antenna, several factors must be taken into consideration. The feeding arrangement must be chosen such that it is simple and properly matches the patch. The feeding networks are divided into two types: direct contact type and indirect contact type. In the first one, the feed line is directly connected to the radiating element, whereas in the second one, they are electromagnetically coupled to input energy to the radiating element. An indirect contact type feeding method has been presented to lessen the problem of enhancement of cross-polarization level that is generated from direct contact type feeding.

Figure 3.2 shows the design of a feeding network used to transmit the input energy efficiently.

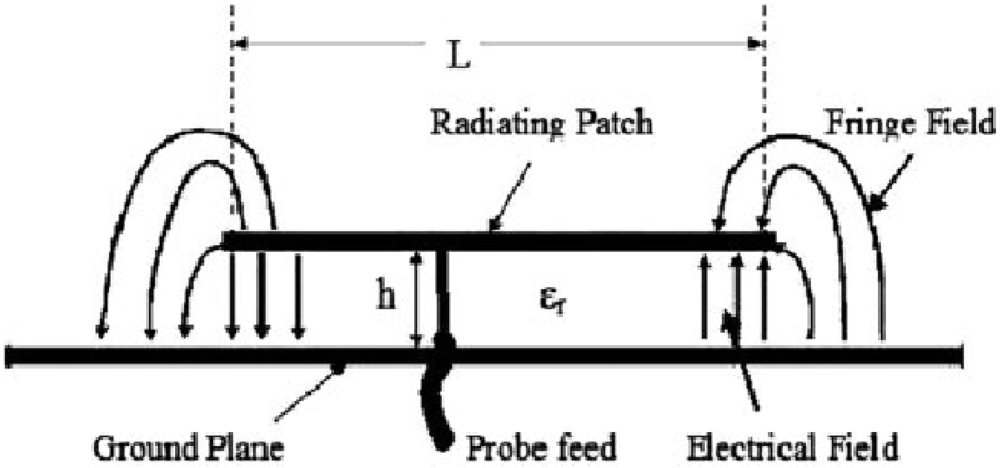


Figure 3.2: Variation of fringing fields.

The mainly used direct contact type feeding techniques are coaxial feed and microstrip feed. The aperture-coupled feed, proximity-coupled feed and co-planar waveguide feed will come under the indirect contact type feeding. All these types of feeding methods are explained in brief. [30]

3.2.1.1. Coaxial Feeding:

Coaxial feeding is mainly applied for transferring the input energy to the patch of a printed antenna. It is the fundamental technique that is used for feeding the microwave power. Figure 3.3 illustrates the coaxial probe feed arrangement with a microstrip patch antenna. The coaxial probe in a coaxial feed system consists of two conductors, of which the internal conductor is associated with the radiating element of the antenna and the external conductor is associated with the ground plane.

The internal conductor provides the matching of input impedance to the characteristic impedance. Coaxial feeding has some benefits such as effortless design, easy fabrication, easy matching and low radiation of spurious waves. On the other hand, the coaxial feed has a drawback of the need for a high soldering precision. The problem that arises when using a coaxial feed in an array structure is the requirement of multiple solder joints.

The coaxial feeding needs a longer probe when a thick substrate is utilized, which raises the surface power and the feed inductance and gives a narrow bandwidth. [30]

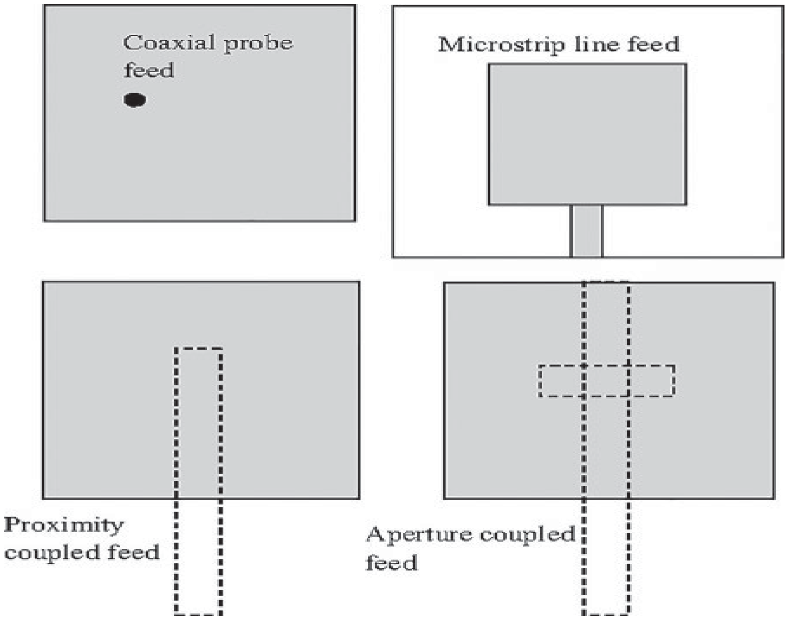


Figure 3.3: Various feeding techniques.

3.2.1.2. Proximity-Coupled Feeding:

Figure 3.3 shows the structure of the proximity- coupled feed, which is one of the recognized mechanisms of electromagnetic coupling. In this type of feed, the input energy is transferred to the patch from the microstrip line via electromagnetic coupling. The proximity-coupled feeding technique consists of a microstrip line, a patch and two different substrates. In this structure, the patch is positioned on the top side of one substrate and the microstrip feed line is placed in between the two substrates of different properties. To analyze the performance of the patch and the feed line individually, this method also provides various choices between different dielectric substrates. The parameters of the two substrates cannot be chosen to be the same to improve antenna operating features. The proximity- coupled feed decreases spurious radiation and increases operating bandwidth. In any case, it desires an exact arrangement between the two layers in multi- layer designing. [30]

3.2.1.3. Aperture-Coupled Feeding:

Figure 3.3 illustrates the structure of the aperture- coupled feeding mechanism. Its geometry contains a ground plane with an aperture slot sandwiched between two dielectric substrates, of which one has a higher- value permittivity and the other has a lower- value permittivity. The radiating patch is located at the outside of one substrate, and the microstrip line is located at the outside of the other substrate. The coupling of input energy between the patch and the feed line is achieved through a small slot cut in the ground plane. Lai et al. [31] reported that in contrast to other feeding techniques, the aperture- coupled feed does not produce spurious radiation. To minimize the cross- polarization which is produced from symmetric configuration, the coupling aperture of the slot is usually situated under the center of the radiating patch. The drawbacks of the aperture- coupled feed due to the multi-layer fabrication are not easy to overcome, because the multi- layer geometry increases the thickness of the antenna system. The advantage of this mechanism is that it allows separate optimization of the feeding process and the radiating patch. A small area of the slot must be chosen to decrease the radiation from the ground surface. In contrast to the probe feed and microstrip line feed, a wide bandwidth is obtained from the aperture-coupled feed with improved polarization purity as reported in. [31]

3.2.1.4. Microstrip Feeding:

In microstrip feeding method, the metallic patch of an antenna is fed via a lesser width of the microstrip line as compared to the patch in the same plane. As a result, a single structure can be found for both the feeding and the patch. Microstrip feeding has some benefits such as easy demonstration, easy matching and simple fabrication. Additionally, it is a decent decision to use this feeding in an antenna array feed network. A lower bandwidth and generation of spurious radiation in the presence of coupling between the patch and the microstrip line are the main disadvantages of this type of feeding mechanism. [30]

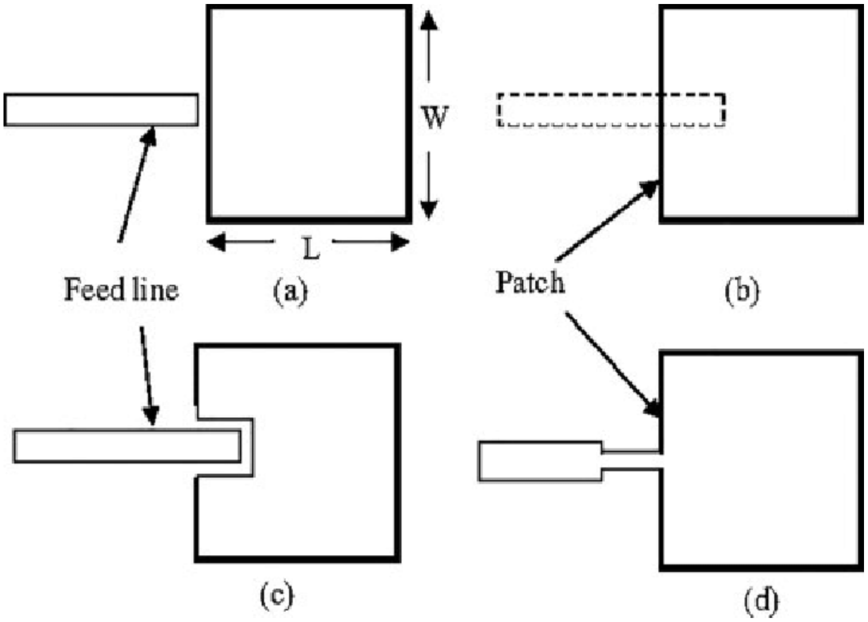


Figure 3.4: Different types of microstrip feed lines.

Microstrip feed can be of the following types:

a) Gap-coupled Feed: As shown in Figure 3.4(a), the microstrip line of the feed is isolated from the patch; an air gap is formed between the 50 Ω microstrip feed line and the patch. The antenna has a disadvantage of coupling between the patch and the 50 Ω of microstrip line of feed.

b) Two-layer Feed: Figure 3.4(b) illustrates that the microstrip line of feed is again isolated from the patch. The location of the feed point is sandwiched between the two layers of the substrate.

c) Inset Feed: As shown in Figure 3.4(c), a thin line of microstrip is introduced within the patch. In this type of microstrip feed method, the feed line is again isolated from the patch. The position of the microstrip line of feed is the same as that used in the coaxial feed. The 50 Ω microstrip feed line is surrounded with an air gap till the feeding point. Further, the inset feed method is more appropriate for an array of feeding networks.

d) Direct Feed: As shown in Figure 3.4(d), the microstrip line of feed is connected with the edge of the radiating patch of the antenna. Direct feed method requires a matching network to compensate for the impedance difference between the patch and the 50 Ω, microstrip feed line. A quarter-wavelength transformer is commonly used as a matching network. [30]

3.2.2. Types of Patch Antennas:

Patch antennas are a type of directional antenna commonly used in wireless communication systems. They are known for their compact size, low profile, and ease of fabrication. Here are some types of patch antennas:

3.2.2.1. Microstrip Patch Antenna:

This is the most common type of patch antenna, consisting of a metal patch mounted on a grounded substrate. The patch is usually made of conductive material like copper, and the substrate can be dielectric material such as FR4 or Rogers.

Microstrip patch antennas are widely used in various applications due to their simplicity and ease of integration. [32]

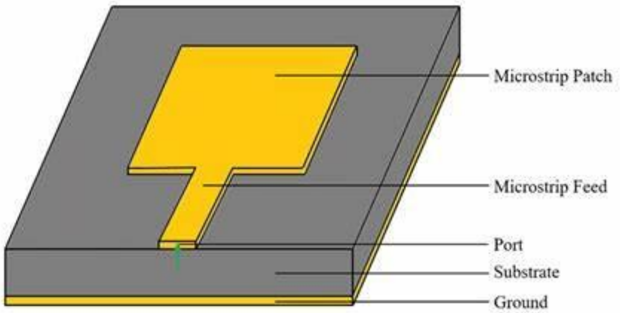


Figure 3.5: Basic Structure of a microstrip patch antenna.

3.2.2.2. Rectangular Patch Antenna:

This type of patch antenna has a rectangular-shaped radiating patch. It is a simple variation of the microstrip patch antenna and offers similar characteristics. Rectangular patch antennas are often used in applications where a wider bandwidth is required compared to microstrip patches. [33]

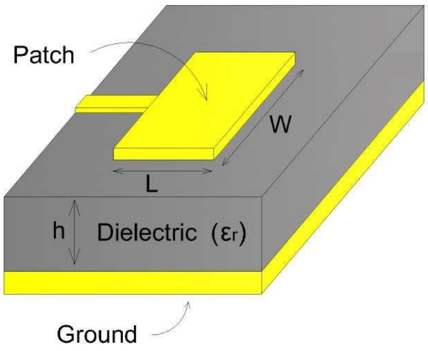


Figure 3.6: Rectangular patch antenna with microstrip.

3.2.2.3. Circular Patch Antenna:

Circular patch antennas have a circular radiating patch. They are often used when circular polarization or Omni-directional radiation patterns are desired. Circular patch antennas find applications in satellite communication, RFID systems, and mobile communication. [34]

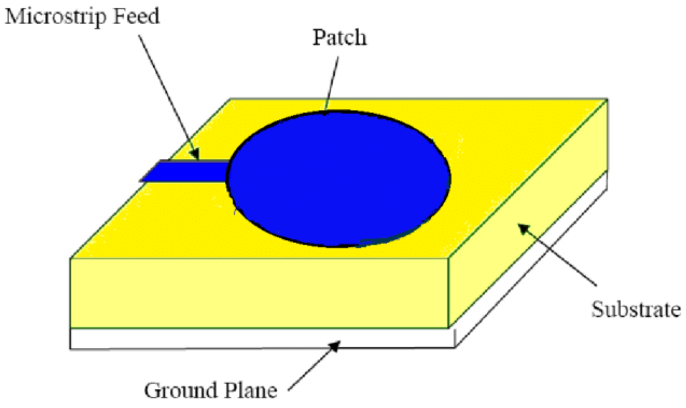


Figure 3.7: Circular Patch Antenna.

3.2.2.4. Dual-polarized Patch Antenna:

Dual-polarized patch antennas are designed to radiate or receive electromagnetic waves in two orthogonal polarization states simultaneously. These antennas are used in MIMO (Multiple Input Multiple Output) systems for improving communication reliability and capacity. [35]

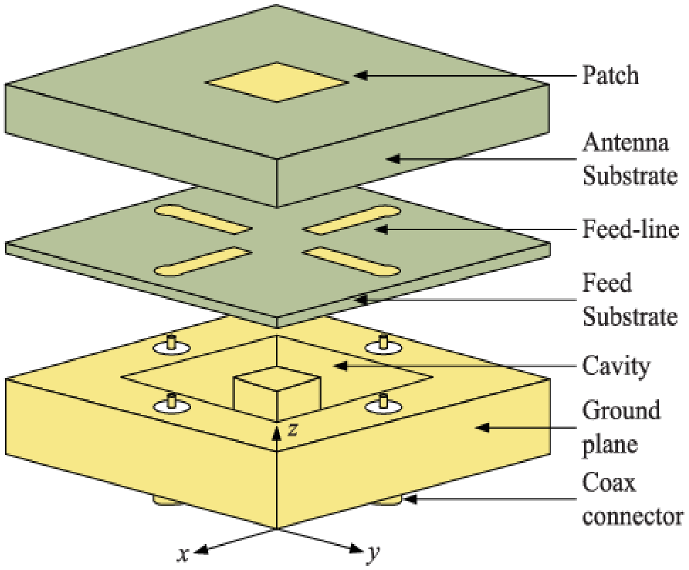


Figure 3.8: Structure of the dual-polarized patch antenna (3D view).

3.2.2.5. Stacked Patch Antenna:

Stacked patch antennas consist of multiple patch layers separated by a dielectric material. This configuration can offer improved performance in terms of bandwidth and gain. [36]

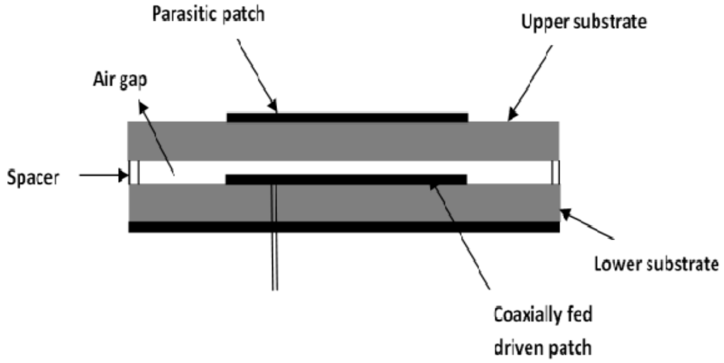


Figure 3.9: Stacked Patch Antenna.

3.3. Microstrip Antennas Designs:

Microstrip antennas consist of a radiating patch printed on a dielectric substrate with a ground plane on the opposite side. The patch and the ground plane are typically connected through a feed line, which may be a microstrip transmission line or a coaxial cable.

The design of microstrip antennas involves determining the dimensions of the radiating patch, the substrate material, the feeding mechanism, and other parameters to achieve desired performance characteristics such as impedance matching, radiation pattern, gain, and bandwidth. Various shapes of patches (rectangular, circular, triangular, etc.) and feeding techniques (microstrip line feed, aperture coupling, proximity coupling, etc.) can be employed to achieve specific design goals. [37]

3.3.1. State of the Art:

The proposed antenna configurations in Figure 3.10(a), increasing the bandwidth of microstrip patch antennas as large as five times a single rectangular patch is obtained while in Figure 3.10(b); a wide operating bandwidth for a single-layer coaxially fed obtained by cutting a U-shaped slot on the patch. This antenna structure with a thick substrate has provided impedance bandwidths of 10% to 40% and high cross polarization in E plane. [38]

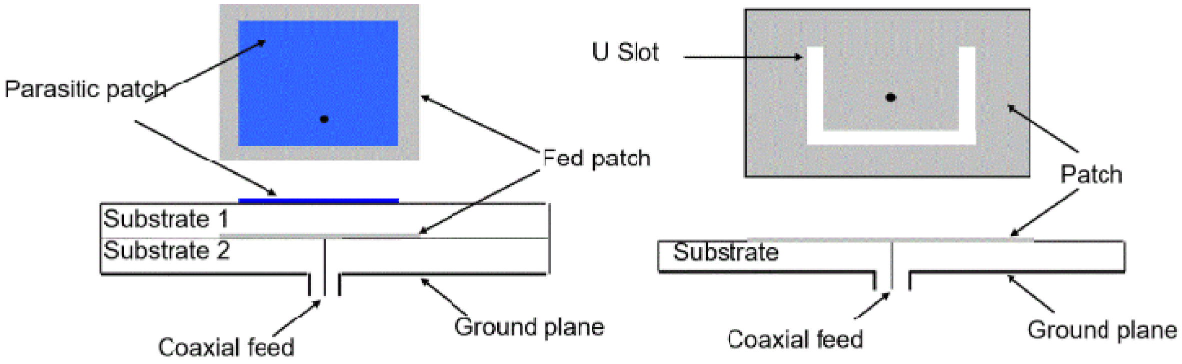


Figure 3.10: Parasitic Patch (a), U-Shaped Slot (b).

The configuration depicted in Figure 3.11 below, is well suited for monolithic phased arrays, where active devices can be integrated on, no radiation from the feed network can interfere with the main radiation pattern since a ground plane separates the two mechanisms. [39]

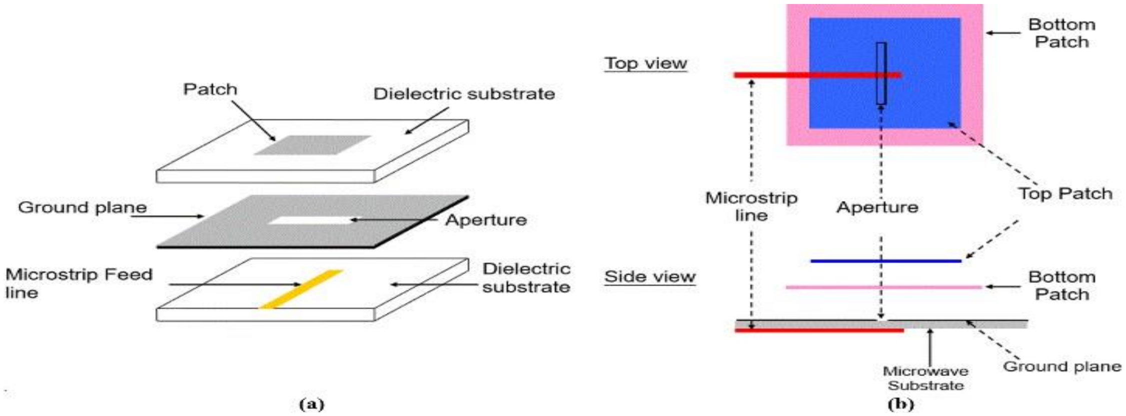
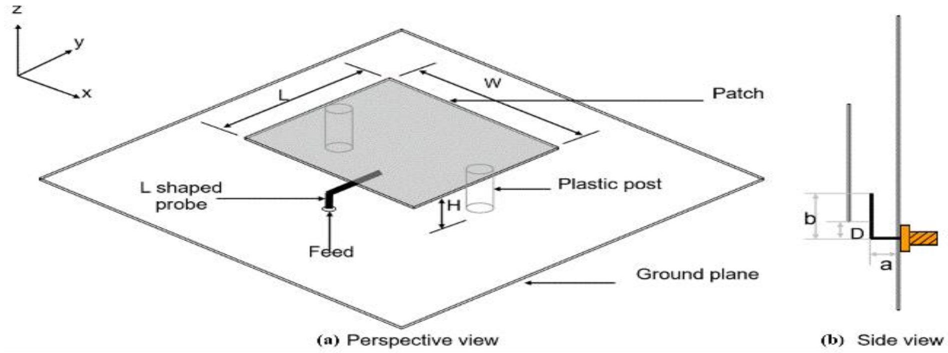


Figure 3.11: Aperture Coupled Patches.

Figure 3.12 shows the horizontal arm of the probe gives a second resonance in conjunction with the patch. It also provides the ability to counteract the reaction of the probe. This patch has only one layer and one patch. The typical bandwidth for foam/air substrates is about 30 %. [40]



(a) Perspective view (b) Side view

Figure 3.12: L-Probe Fed Patch Antenna.

As shown in Figure 3.13, It is found The incorporation of a U- slot in the patch can provide a flat input resistance and a linear input reaction across a wider bandwidth than the conventional patch antenna The impedance matching frequency of the antenna can be varied by placing a variable capacitor and an inductor at the input of the antenna. It is suitable for use in reducing the crosstalk from adjacent channels in multichannel system. [41]

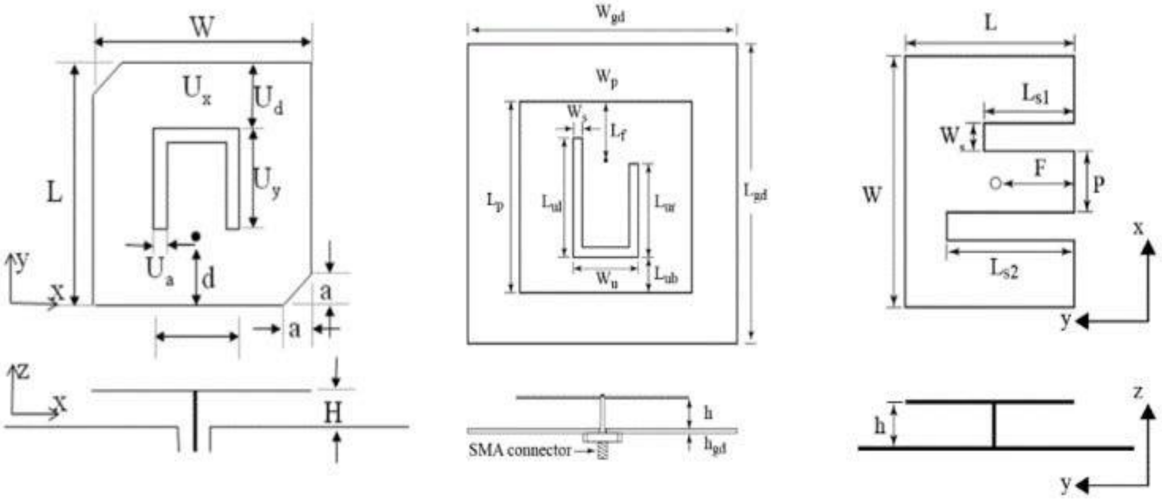


Figure 3.13: Three Relatively Wideband Single Feed CP Patch Antennas.

In Figure 3.14 Orthogonal polarization is present in both modes. A feeding network is designed to provide the two ports with the same amplitude but phase quadrature excitation. A bandwidth of approximately 10 percent while maintaining a thin substrate. [42]

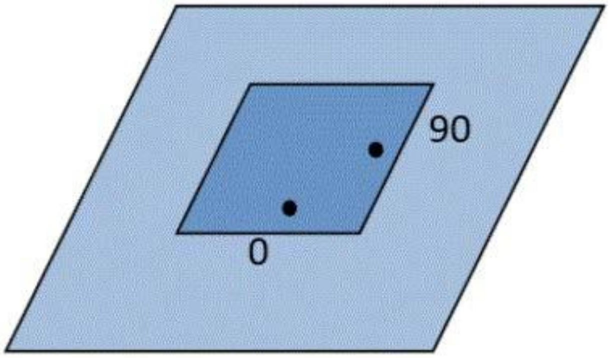


Figure 3.14: Dual Feed CP Patch Antenna.

3.3.2. Achievements of Microstrip Antennas:

Microstrip antennas have several notable achievements and advantages in the field of antenna technology. Some of these achievements include:

a) Compact Size: Microstrip antennas are known for their compact size, making them suitable for integration into small devices and systems where space is limited.

b) Low Profile: Due to their planar structure, microstrip antennas can be designed to have a very low profile, making them ideal for applications where aerodynamics or aesthetics are important.

c) Lightweight: Microstrip antennas are lightweight because they are fabricated on thin substrates, making them suitable for weight-sensitive applications such as aerospace and automotive applications.

d) Low Cost: Microstrip antennas can be fabricated using standard printed circuit board (PCB) manufacturing techniques, which are relatively inexpensive compared to other types of antennas, making them cost-effective for mass production. [43]

3.3.3. Limitations of Microstrip Antennas:

While microstrip antennas offer numerous advantages, they also have some limitations that should be considered in their design and implementation. Some of these limitations include:

a) Narrow Bandwidth: Microstrip antennas typically have a narrow bandwidth compared to other types of antennas, limiting their performance in applications requiring operation over a wide frequency range

b) Low Efficiency: Microstrip antennas may suffer from lower efficiency, especially when miniaturized or operating at higher frequencies, impacting their overall performance.

c) Susceptibility to Environmental Effects: Microstrip antennas can be sensitive to changes in their environment, affecting their performance. Variations in substrate properties, nearby structures, or surrounding materials can impact their effectiveness.

d) Limited Power Handling: Microstrip antennas may have limited power handling capabilities, especially at higher frequencies, restricting their use in high-power applications.

e) Mutual Coupling: In array configurations, microstrip antennas may experience mutual coupling between adjacent elements, degrading the overall performance of the antenna. [44]

Despite these limitations, microstrip antennas remain widely used in various applications due to their compact size, low profile, ease of fabrication, and suitability for integration into modern electronic devices. Designers should carefully consider these limitations and address them through proper design techniques and optimization strategies to maximize the performance of microstrip antennas for specific applications.

CHAPTER 4

SIMULATION AND RESULTS

4.1. Introduction:

In the modern world of wireless communication networks, patch antennas serve a purpose that is of the utmost importance, therefore, essential to how they work. The construction of a PIFA Antenna is not overly complicated and uses a microstrip fabrication technology that is more frequently applied. The patch can be configured in about any shape imaginable. [45]

A PIFA Antenna tailored for WLANs applications underwent design and analysis utilizing the High-Frequency Structural Simulator (HFSS) and optimizing by Python (PY) Scripting.

HFSS provides an intuitive interface facilitating simplified design input, an accurate field solving engine with adaptive solutions, and a robust post-processor for unparalleled insights into electrical performance. The software automatically generates and computes output results, incorporating the analysis of key parameters such as return loss, gain, and directivity.

Evaluation and optimization of a patch antenna using Python scripting involves employing algorithms and numerical techniques to make slots in the patch of antenna in order to achieve desired performance goals.

The objective is to obtain a high directivity with good gain and low losses for wireless local area networks (WLAN).

4.2. PIFA Antenna Design:

A new design structure patented in 1955 was the microstrip antenna, also known as the patch antenna. In a microstrip antenna, there is a layer of conductive material on each side of the substrate and insulating material. The term "ground plane" refers to the lower conducting surface, while "patch" refers to the upper conducting plate. Both of these surfaces are conductive. Because the manufacturing process of printed circuit boards and microstrip antennas is similar, the microstrip antennas are also referred to as "printed antennas." The size and shape of the patch are two of the most important things that affect how well the microstrip antenna works. The length, width, and thickness of the substrate, the dielectric constant of the substrate material, and where the feed line is placed all affect how well the MPA works. An antenna device is connected to a source and a load terminal. The antenna matches the characteristic impedance of the two terminals. An impedance-matching device is a term that's used to refer to this piece of equipment. The antenna converts the electrical signals into electromagnetic waves to be transmitted. At reception time, it turns electromagnetic waves into electrical impulses, which is the opposite of what it did to send the signal. The rising demand for wireless communication devices and the downsizing of these systems have made it more challenging to design antennas in today's world. This demand has completed the design of antennas more challenging. However, these antennas have several limitations, the most notable of which are their narrow BW and weak gain. [46]

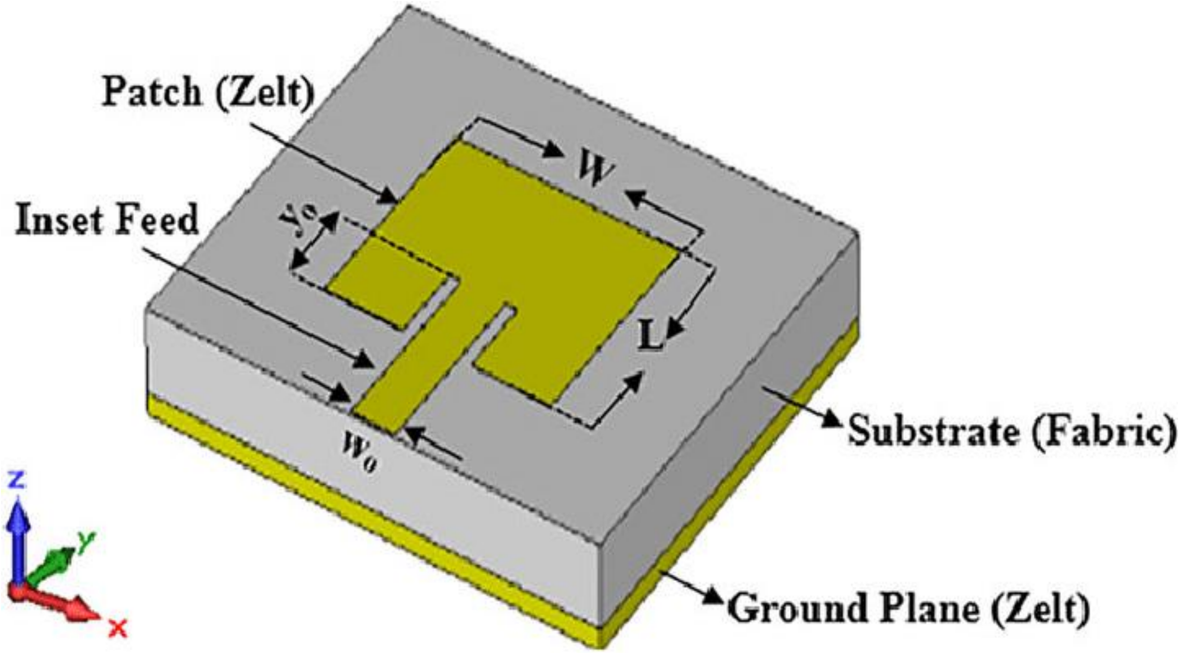


Figure 4.1: Dual Feed CP Patch Antenna.

The following relationships can be utilized to calculate the dimensions of the antenna. [47]

- **Width of the Patch:**

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where, C: free space velocity of light

fr: relative permittivity of substrate

εr: resonating frequency

- **Effective Dielectric Constant:**

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

Where, h: Thickness of the substrate

W: width of the patch

- **Effective Length:**

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

- **Patch Length Extension:**

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

- **Length of the Patch:**

$$L = L_{eff} - 2\Delta L$$

4.3. Python Scripting Development:

Python scripting development encompasses a multifaceted utilization of the Python programming language to construct a wide array of scripts and applications tailored to meet diverse needs across various industries and domains. Python's intrinsic characteristics of flexibility, readability, and extensive libraries position it as the optimal choice for a myriad of tasks, ranging from automating repetitive processes to analyzing complex datasets and crafting sophisticated software solutions. At the onset of Python scripting endeavors, developers embark on the journey by crafting code within their preferred text editors or Integrated Development Environments (IDEs), leveraging an arsenal of features such as code completion, syntax highlighting, and debugging tools to expedite the development process and ensure code integrity. As the scripting project evolves and requirements become more nuanced, developers seamlessly integrate an array of third-party libraries and frameworks to extend the functionality of their scripts, optimize performance, and access specialized tools tailored to specific tasks.

Moreover, Python's versatility transcends conventional software development paradigms and finds its niche in addressing specialized challenges, such as the design and analysis of Planar Inverted-F Antennas (PIFAs). PIFAs, characterized by their compact size and efficient radiation properties, play a pivotal role in modern wireless communication systems. Python scripting emerges as a powerful ally in this domain, enabling engineers and researchers to delve into the intricate world of antenna design with unparalleled precision and efficiency. By leveraging Python's rich ecosystem of scientific computing libraries, such as NumPy, SciPy, and Matplotlib, engineers can seamlessly model electromagnetic behaviors, optimize antenna parameters, and visualize simulation results with unparalleled clarity. Furthermore, specialized libraries such as scikit-rf provide dedicated tools for microwave network analysis and design, empowering developers to fine-tune the performance of PIFA antennas with unprecedented accuracy and efficacy. [48]

4.4. Design of a Patch Antenna for WLAN Applications:

Patch Antenna for Wireless Local Area Networks applications has been designed and analyzed using HFSS software. The substrate material employed is FR4 glass epoxy, boasting a relative permittivity of 4.4. The width of the patch is 38 mm and length is 29.4 mm. The length of the feed line is 24.8 mm. feed width is 3 mm and feed insertion of 9.5 mm, feed gap of 1 mm.

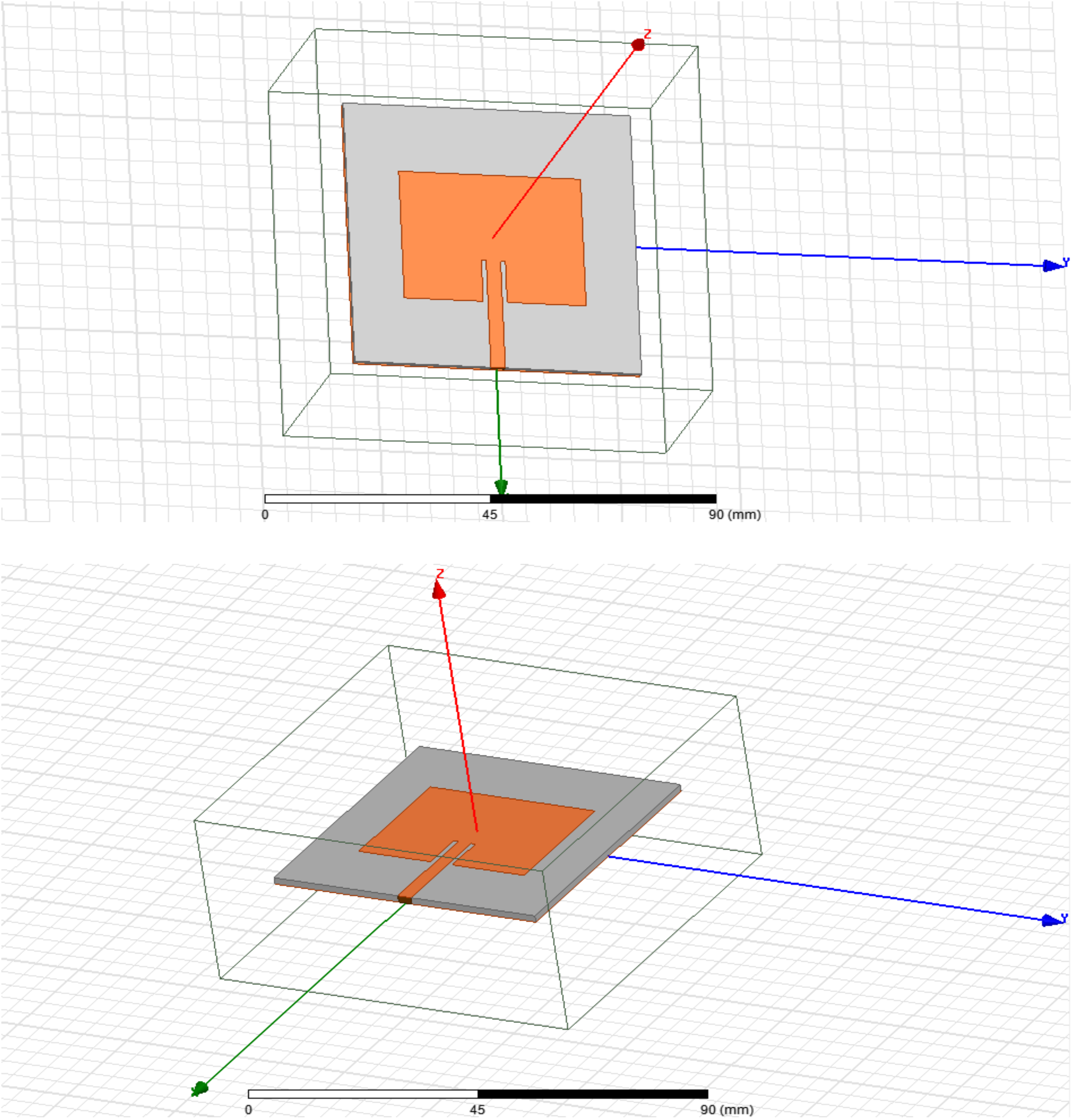


Figure 4.2: The Patch Antenna Structure.

4.4.1. Simulated Antenna Results and Discussion:

a) Return Loss: In communication devices, the radiation that bounces off the antenna is called "return loss," and the term "return loss" is used in communication devices. Return loss happens when the coaxial cable or the system for sending power does not fit well. This can take place when there is a mismatch in the impedance. The S-parameter tells you how much power is reflected from the antenna have input port and how much energy it gives off after reflecting specific signals. [49]

The reflection coefficient is one of the most important things to consider when figuring out how much power an antenna can send out in all directions. If you have a good patch antenna, need a return loss value of less than -10 dB for effective communication. The S-parameter says what the antenna's resonance frequency is. Figure 4.3 shows value of S-parameter. The PIFA antenna constructed with FR-4 has a return loss of (S11= -32.6269) while it is operating at its resonance frequency of 2.2 GHz.

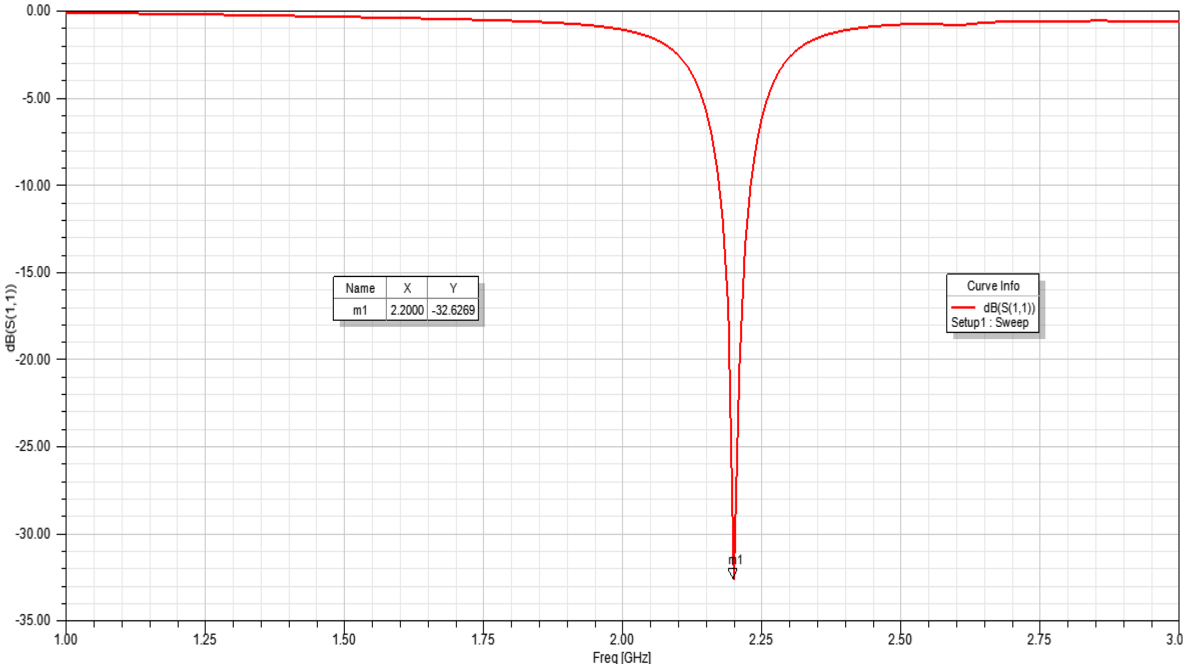


Figure 4.3: Return Loss of Patch Antenna.

b) Voltage Standing Wave Ratio (VSWR): The VSWR is a way to measure how well radio frequency (RF) power is sent from a power source to a load along a transmission line. Figure 4.4 shows the calculated value for the antenna's VSWR at 2.2 GHz. The VSWR for FR-4 material comes in at 0.4060.

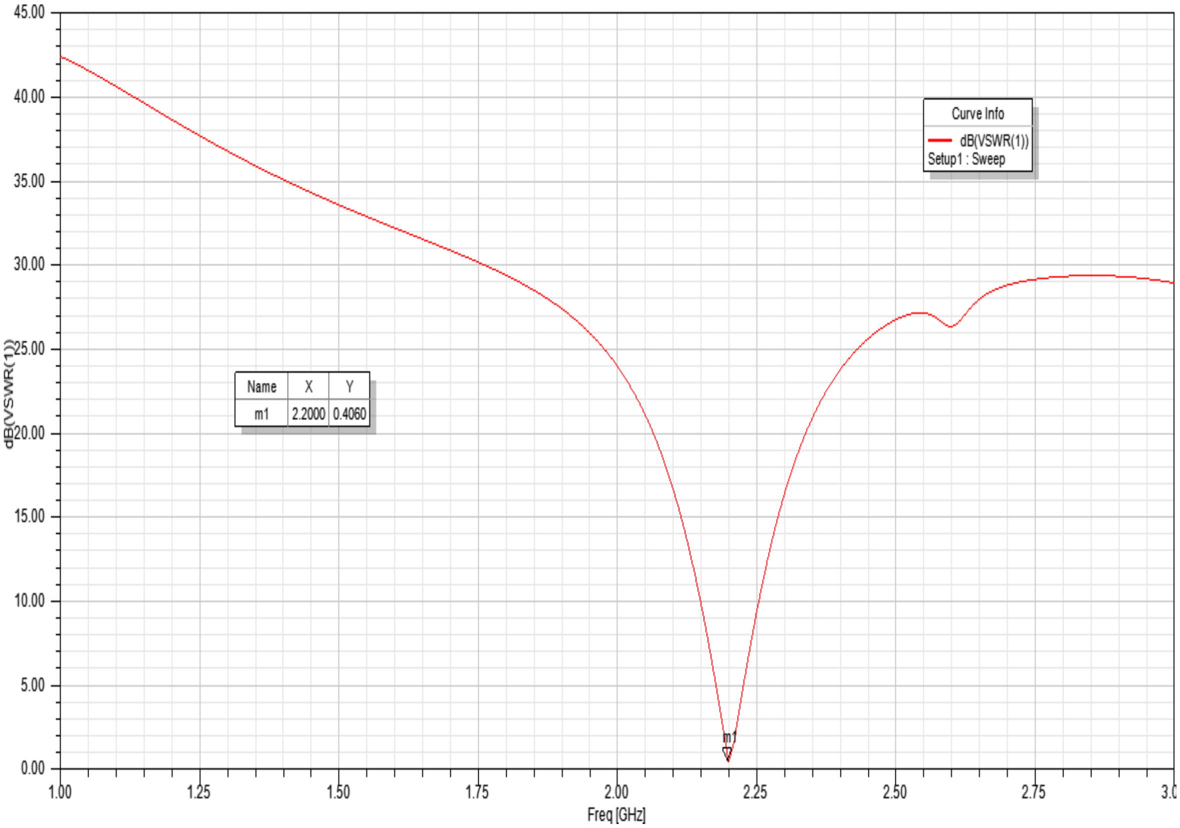


Figure 4.4: VSWR of Patch Antenna.

c) Gain: Gain is defined as the difference between the power density of a directional antenna at every place and the power density of an isotropic antenna at the same point when both antennas are fed by the same power source. The gain can measure the amount of energy transferred to the main lobe. [50]

Figure 4.5 show how well the suggested antenna model works regarding the gain of the PIFA antenna. The peak gain is 1.9678 dB.

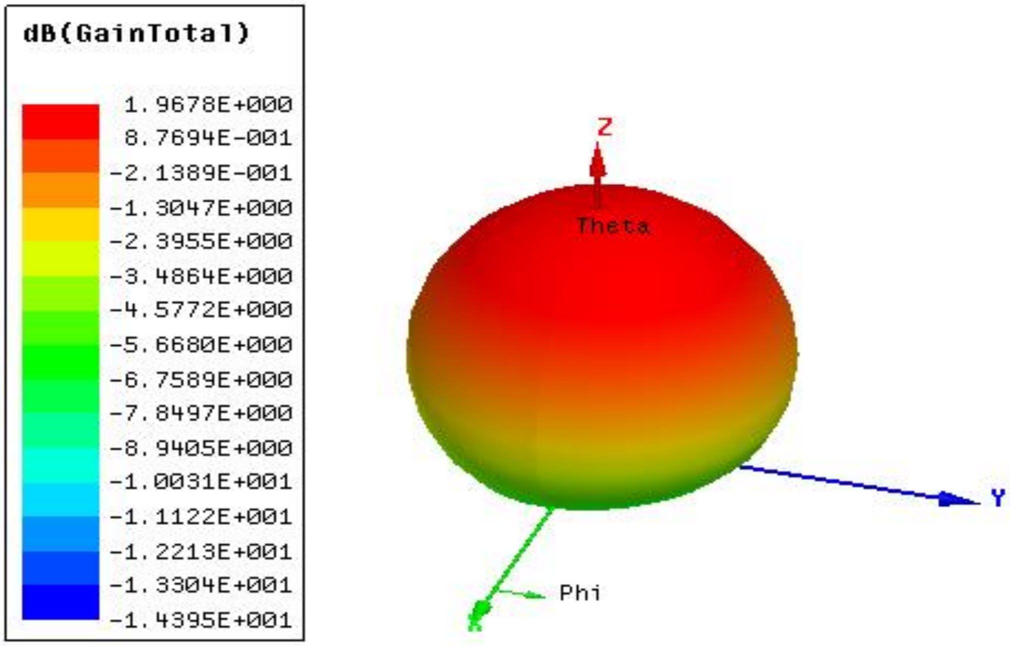


Figure 4.5: 3D Polar Plot of Patch Antenna.

d) Radiation Pattern: The radiation pattern of the PIFA Antenna is shown in Figure 4.6, displaying the E-plane and H-plane fields.

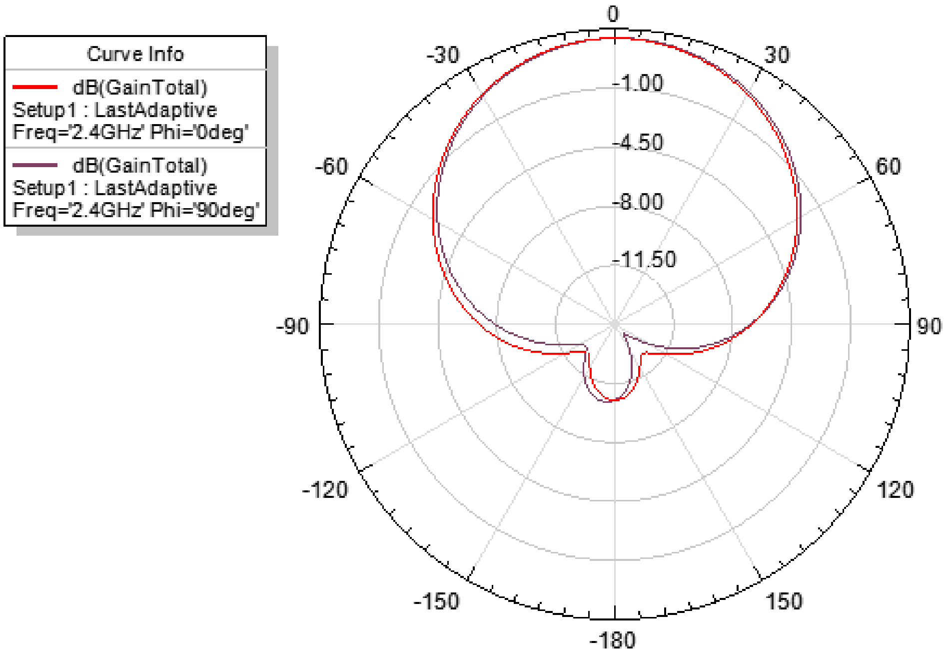


Figure 4.6: Radiation Pattern of Patch Antenna.

4.5. Evaluation and Optimizing using Python:

Performance of the PIFA Antenna for Wireless Local Area Networks applications has been optimized by first adding two slots using Python scripting, and then further enhancing it by incorporating four slots through the same method.

4.5.1. Two-Slot Patch Antenna by Python Scripting:

Here 2 slots are added by python scripting and they have the same dimensions in order to optimize the antenna performance. The length of slots is 4 mm, the width is 8 mm. The distance between them is 1 mm.

```
name = 0
for x in range(-10,0,5):
        name+=1
        oEditor.CreateBox(
            [
                "NAME:BoxParameters",
                "XPosition:="       , str(x)+"mm",
                "YPosition:="       , "-4mm",
                "ZPosition:="       , "1.6mm",
                "XSize:="       , "4mm",
                "YSize:="       , "8mm",
                "ZSize:="       , "0mm"
            ],
            [
                "NAME:Attributes",
                "Name:="        , "Box"+str(name),
                "Flags:="       , "",
                "Color:="       , "(143 175 143)",
                "Transparency:="    , 0,
                "PartCoordinateSystem:=", "Global",
                "UDMId:="       , "",
                "MaterialValue:="   , "\"vacuum\"",
                "SolveInside:="     , True
            ])
        oEditor.Subtract(
            [
                "NAME:Selections",
                "Blank Parts:="     , "patch",
                "Tool Parts:="      , "Box"+str(name)
            ],
            [
                "NAME:SubtractParameters",
                "KeepOriginals:="   , False
            ])
```

Figure 4.7: Python Scripting of making Two-Slot in Patch Antenna.

Using Python Scripting above, we have designed Two-Slot Patch Antenna.

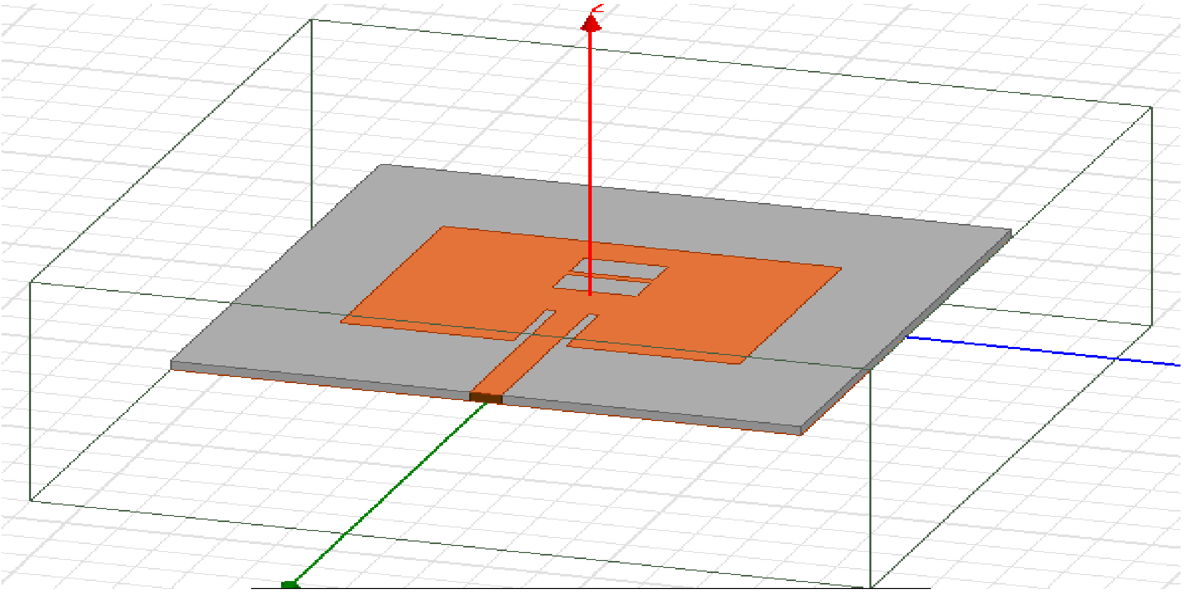


Figure 4.8: Two-Slot Patch Antenna Design.

4.5.1.1. Simulated Antenna Results and Discussion:

a) The antenna resonates at 2.3200 GHz with parameter (return loss) value of −28.2416 dB, indicating excellent performance.

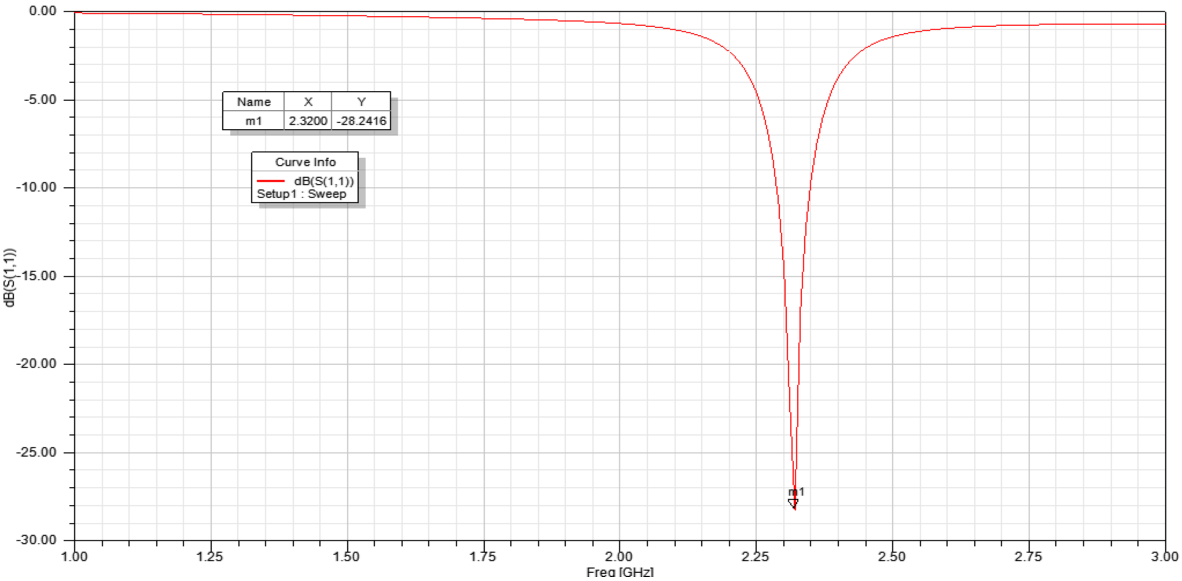


Figure 4.9: Return Loss of Two-Slot Patch Antenna.

b) From figure 4.10, it is clear that the value of VSWR at 2.3200 GHz is 0.6729, meaning the antenna is very well-matched to the transmission line impedance.

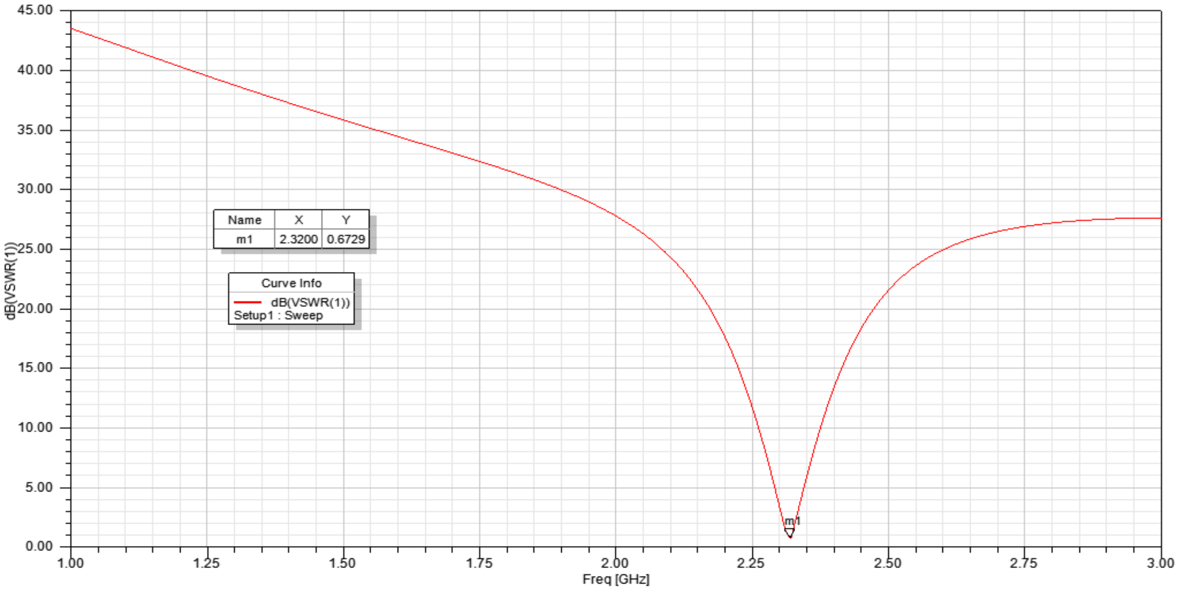


Figure 4.10: VSWR of Two-Slot Patch Antenna.

c) The peak gain of the patch antenna is 2.2627 dB. This indicates that the antenna is capable of concentrating its radiation pattern in a particular direction.

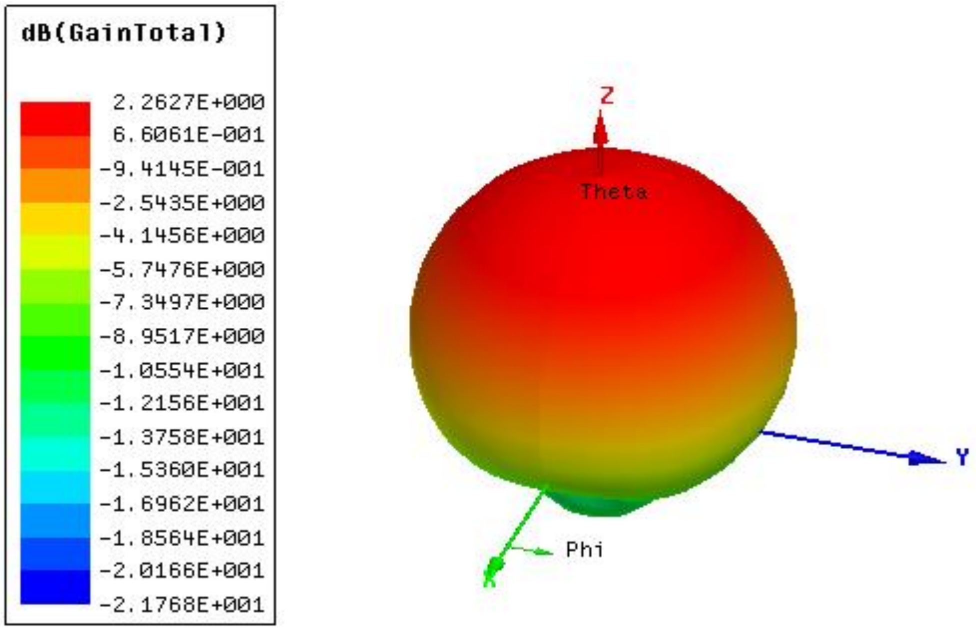


Figure 4.11: 3D Polar Plot of Two-Slot Patch Antenna.

d) The radiation pattern of antenna is shown in Figure 4.12. In this radiation pattern both E and H plane are presented.

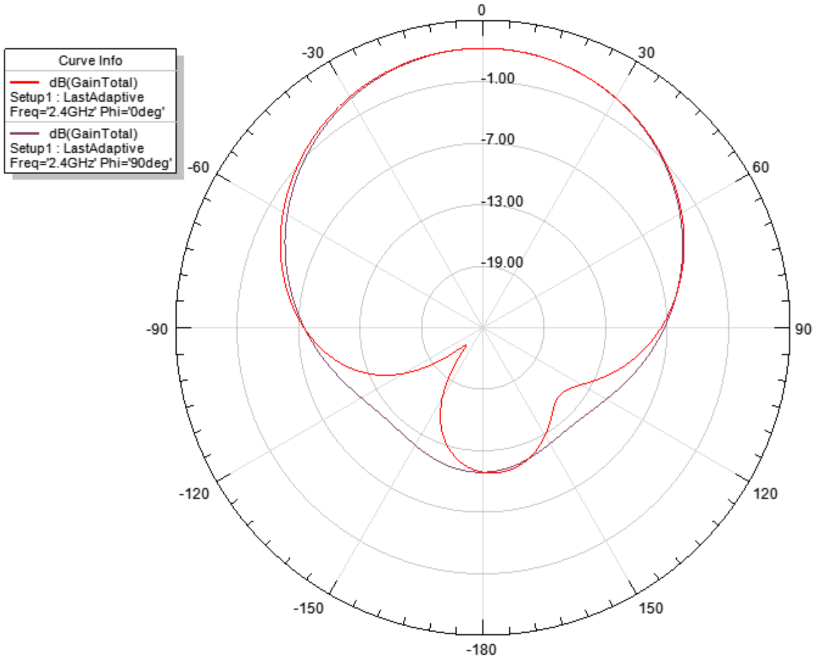


Figure 4.12: The Radiation Pattern of Two-Slot Patch Antenna.

4.5.2. Four-Slot Patch Antenna by Python Scripting:

We have designed Four-Slot Patch Antenna using Python Scripting for Optimizing the Performance of Antenna as Figure 4.13 Shown.

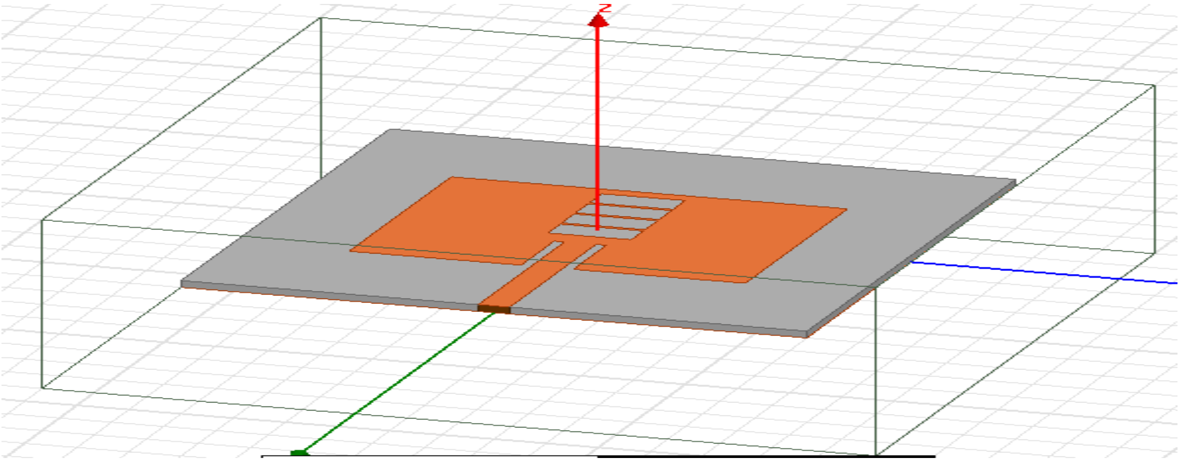


Figure 4.13: Four-Slot Patch Antenna Design.

Here 4 slots are added by python scripting and they have the same dimensions in order to increase the antenna performance. The length of slots is 3.5 mm, the width is 8 mm. The distance between them is 0.5 mm.

Python Scripting of Adding Four-Slot in Patch Antenna is sown in Figure 4.14.

```
name = 0
for x in range(-13,3,4):
        name+=1
        oEditor.CreateBox(
            [
                "NAME:BoxParameters",
                "XPosition:="       , str(x)+"mm",
                "YPosition:="       , "-4mm",
                "ZPosition:="       , "1.6mm",
                "XSize:="       , "3.5mm",
                "YSize:="       , "8mm",
                "ZSize:="       , "0mm"
            ],
            [
                "NAME:Attributes",
                "Name:="        , "Box"+str(name),
                "Flags:="       , "",
                "Color:="       , "(143 175 143)",
                "Transparency:="    , 0,
                "PartCoordinateSystem:=", "Global",
                "UDMId:="       , "",
                "MaterialValue:="   , "\"vacuum\"",
                "SolveInside:="     , True
            ])
        oEditor.Subtract(
            [
                "NAME:Selections",
                "Blank Parts:="     , "patch",
                "Tool Parts:="      , "Box"+str(name)
            ],
            [
                "NAME:SubtractParameters",
                "KeepOriginals:="   , False
            ])
```

Figure 4.14: Python Scripting of making Four-Slot in Patch Antenna.

4.5.2.1. Simulated Antenna Results and Discussion:

a) The antenna resonates at 2.3100 GHz with parameter (return loss) value of −19.8772 dB, indicating excellent performance and reducing signals reflections.

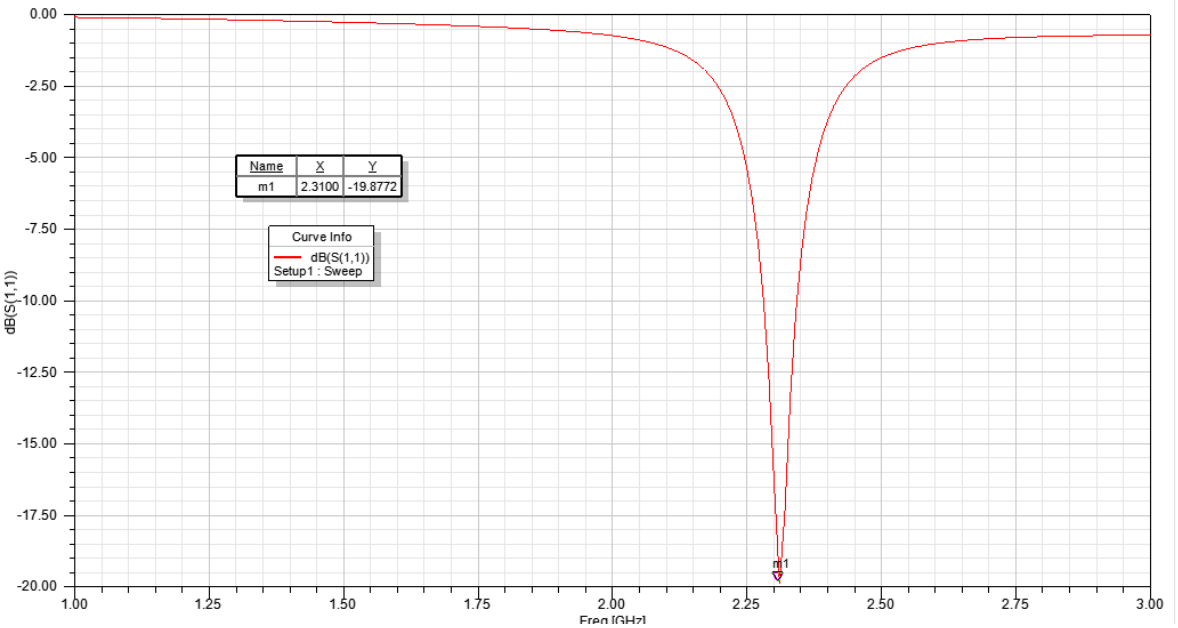


Figure 4.15: Return Loss of Four-Slot Patch Antenna.

b) Figure 4.16 shows the calculated value for the antenna's VSWR at 2.3100 GHz. The VSWR comes in at 1.7680.

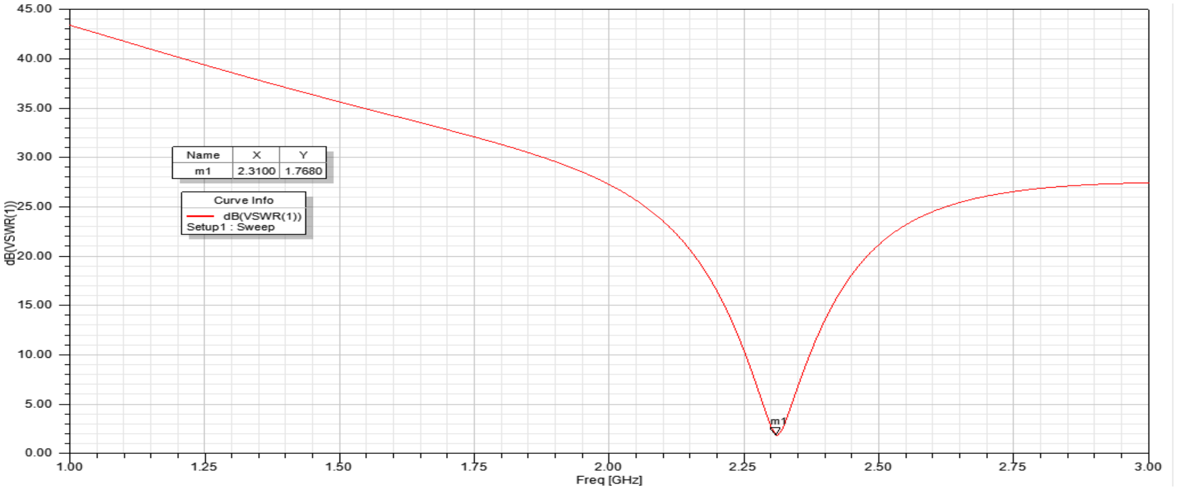


Figure 4.16: VSWR of Four-Slot Patch Antenna.

c) The peak gain of the patch antenna is 2.0893 dB. This indicates that the antenna is capable of concentrating its radiation pattern in a particular direction.

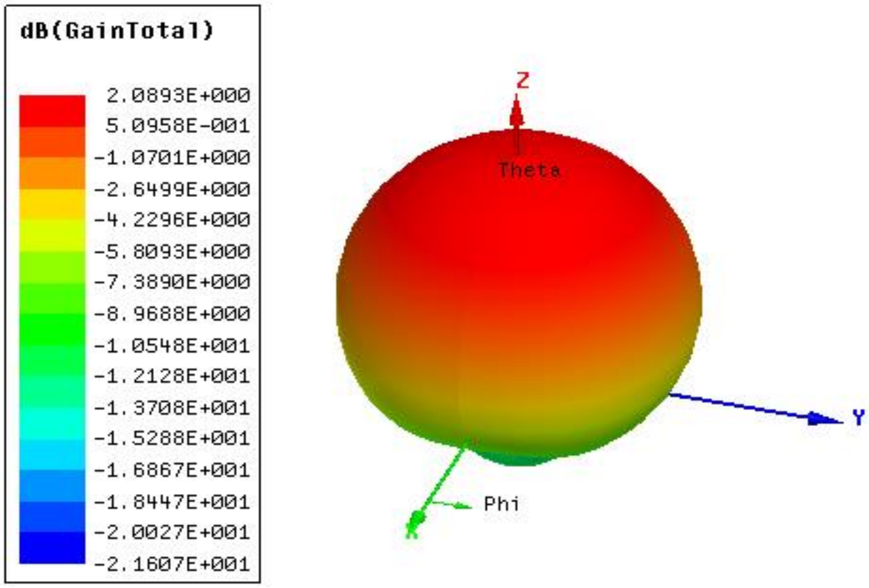


Figure 4.17: 3D Polar Plot of Four-Slot Patch Antenna.

d) The radiation pattern of the PIFA Antenna is shown in Figure 4.18, displaying the E-plane and H-plane fields.

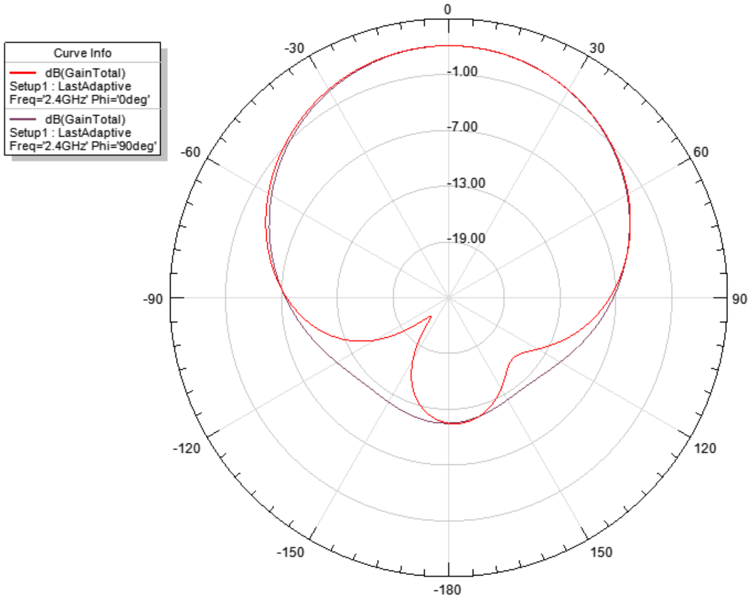


Figure 4.18: Radiation Pattern of Four-Slot Patch Antenna.

4.6. Comparison of Results:

Microstrip patch antenna is configured with different number of slots and has been analyzed and various electromagnetic responses have been achieved. Various factors have been taken into consideration including substrate choice, feeding technique and dimensions. All developed structures presents high electromagnetic performance, terms of good directivity and gain and low return losses to answer WLAN applications requirements especially in 2.4 GHz as displays the following table:

Parameters	**Patch Antenna**	**Two-Slot Patch Antenna**	**Four-Slot Patch Antenna**	**Desired Parameters**
Operating Frequency(GHz)	2.2000	2.3200	2.3100	2.20 - 2.45
Return Loss(dB)	-32.6269	-28.2416	-19.8772	≤-10
VSWR	0.4060	0.6729	1.7680	≤1.9
Gain(dB)	1.9678	2.2627	2.0893	≤15

Table 4.1: Results Comparison.

General Conclusion

In conclusion, the utilization of Python scripting in the design of planar antennas for wireless local area networks (WLANs) offers significant advantages and insights. Through this study, several findings have emerged, shedding light on the effectiveness and efficiency of Python as a tool for antenna design. Python's versatility and extensive libraries provide engineers with a powerful platform to develop and optimize planar antennas tailored to WLAN requirements.

The study on employing Python scripting in the design of planar antennas for wireless local area networks (WLANs) yields several significant benefits. Firstly, it enhances the efficiency of the antenna design process, allowing engineers to develop and optimize planar antennas more rapidly and effectively. This efficiency stems from Python's extensive libraries and tools, which provide a versatile platform for customization and adaptation to meet specific WLAN requirements. Additionally, the study contributes to cost-effectiveness by reducing reliance on expensive proprietary software, making antenna design accessible to a broader range of researchers and practitioners. Furthermore, through rigorous validation and refinement of simulation results, the study advances our understanding of planar antenna design principles and their practical applications in WLANs.

However, this study is not without its limitations. While Python scripting offers numerous benefits, it requires a solid understanding of both antenna theory and programming principles. Additionally, the accuracy of the simulation results heavily relies on the precision of the models and algorithms implemented. Therefore, thorough validation against experimental data is crucial to ensure the reliability of the designed antennas.

Throughout the process, various obstacles were encountered, including computational resource constraints, algorithm complexity, and the need for expertise in both antenna engineering and programming. Overcoming these obstacles necessitated optimizing computational resources, fostering expertise through collaboration, and validating simulation results rigorously.

In this study, planar antenna is configured with different number of slots using FR-4 substrate material having a relative permittivity equals to 4.4. PIFA Antenna and Two-Slot patch antenna and Four-Slot patch antenna are developed to operate at 2.4 GHz for WLAN applications. Implementing a more number of slots into the patch leads to improve the network directivity and gain and reduce the return losses.

Looking ahead, the perspectives for planar antenna design using Python scripting are promising. As computational resources continue to advance and Python libraries evolve, the efficiency and accuracy of antenna design processes are expected to improve further. Moreover, the integration of machine learning techniques holds the potential to automate and optimize antenna design tasks, paving the way for faster and more innovative solutions in WLAN deployment.

In summary, while there are challenges and limitations inherent in the use of Python scripting for planar antenna design in WLANs, the benefits are substantial. With careful consideration of these factors and continued advancements in technology and methodology, Python scripting stands as a valuable tool for engineers seeking to develop high-performance planar antennas for wireless communication systems.

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