A

PROJECT REPORT

ON

"A Novel Design of Parasitically Gap Coupled Patches Forming Elliptical Patch Antenna for Broadband Performance"

Submitted for the partial fulfillment of award of

BACHELOR OF TECHNOLOGY
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By

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Candidate's Declaration

I hereby declare that the work which is being presented in this dissertation entitled as **"A NOVEL DESIGN OF PARASITICALLY GAP COUPLED PATCHES FORMING AN ELLIPTICAL PATCH ANTENNA FOR BROADBAND PERFORMANCE"**, towards the partial fulfillment for the award of Degree of Bachelor of Technology in Electronics & Communication Engineering, submitted in the Department of Electronics & Communication Engineering, Institute of Engineering & Technology, Bundelkhand University, Jhansi, is an authentic record of my work , under the kind guidance of **ER. RAJESH VERMA**, Lecturer, Department of Electronics & Communication Engineering, Institute of Engineering & Technology, Bundelkhand University, Jhansi.

I have not submitted the matter embodied here for the award of any other degree .

Date: **28 MAY 2024** **NIKHIL SHUKLA (201361031032)**

Certificate

Certified that Group has carried out the project work presented in this report entitled "**A NOVEL DESIGN OF PARASITICALLY GAP COUPLED PATCHES FORMING AN ELLIPTICAL PATCH ANTENNA FOR BROADBAND PERFORMANCE**" for the partial fulfillment for the award of degree of **Bachelor of Technology** from Bundelkhand University, Jhansi. The work is carried out by Students themselves and the contents of the work do not form the basis for the award of any other degree to the candidate or to anybody else.

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Certificate

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NIKHIL SHUKLA

Abstract

An ellipse-shaped single layer assembly of gap-coupled devices designed for broadband performance is shown in this communication. Out of the five patches examined in this assembly, one edge-truncated elliptical patch is surrounded by two pairs of patches with distinct patch areas. The centre patch is gap linked to the other patches parasitically and supplied via an inset feed system. In the middle lies a truncated elliptical patch. An improved impedance bandwidth of 0.57 GHz (or 10.9%) with respect to the centre frequency of 5.23 GHz is obtained with this setup. Because it stimulates three resonant modes, this design offers higher gain and bandwidth than an elliptical patch antenna in the typical configuration. The suggested patch arrangement's simulated radiation patterns show that every patch has the same form and that the patch assembly is where the majority of the radiation is focused.

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CHAPTER-1
INTRODUCTION

Radar systems, wireless communication, radio and television transmission, and other forms of communication often employ antennas, which are devices designed to transmit or receive electromagnetic waves [24]. Scientists like James Clerk Maxwell, who created the mathematical formulas defining electromagnetic waves, set the theoretical foundation for the idea of antennas in the late 19th century.

Antenna applications for practical use grew in popularity in the early 1900s. Antennas for wireless telegraphy were first used in practice by the Italian engineer and inventor Guglielmo Marconi. Marconi carried out groundbreaking research in the 1890s that resulted in the creation of the first functional radio communication systems. The notable transatlantic radio transmission that took place in 1901 as a result of his work proved that long-distance wireless communication was feasible [24].

The development of antenna technology since Marconi's time has been largely fueled by improvements in electronics and telecommunications. In order to accommodate a wide range of applications in contemporary communication systems and technologies, antennas are now available in a variety of shapes and sizes, such as dipole, parabolic, and phased array antennas.

In many contemporary wireless communication systems, a microstrip patch antenna is a small, adaptable kind of radio frequency antenna [15]. This antenna design, which changed the industry when it was first introduced in the 1970s, was lightweight, low profile, and simple to integrate into electronic equipment. It is usually made of a thin metallic patch on one side of a dielectric substrate, and depending on its size, it may be made to function at a certain frequency [15]. Because of its easy-to-understand form and compatibility with integrated circuit technology, it has been widely used in applications including wireless networking, radar systems, mobile phones, and satellite communication. Because of its benefits in terms of weight, size, and price, microstrip patch antennas are a common option for establishing dependable wireless connection in a variety of contemporary communication equipment.

There are many varieties of microstrip patch antennas, each designed for a particular need. Circular patches give a wider bandwidth, while rectangular patches are often employed for simplicity. Hexagonal and triangular patches also provide distinctive radiation patterns [15]. Common feeding configurations include microstrip line-fed and probe-fed. Microstrip patch antennas are small, flexible, and widely used in a variety of technologies, including mobile devices and satellite communication, demonstrating their adaptability to the needs of contemporary wireless communication systems.

1.1 Antenna

Antennas are vital to communications because they allow wireless information exchange. In the context of telecommunications, an antenna is a transducer that converts electrical impulses into electromagnetic waves for transmission or reception [25]. An antenna's functioning is based on the fundamental concepts of electromagnetic. When an alternating current flows through the antenna, oscillating electric and magnetic forces are created, which are then propagated throughout the surrounding environment as electromagnetic waves.

In satellite communication, antennas are essential components of both ground-based stations and satellites. Ground-based antennas are responsible for transmitting signals to satellites and receiving signals from them. Satellite antennas, on the other hand, are designed to communicate with ground stations and other satellites [11]. The type of antenna used in satellite communication depends on various factors, including the application, frequency band, and specific requirements of the communication link.

Fig.1.1: Parabolic antenna

In satellite communication, parabolic antennas—also referred to as dish antennas—are often used [22]. The feed or feedhorn, a smaller antenna element situated near the focal point, receives incoming or outgoing signals by the employment of a dish-shaped reflector in these antennas. High gain, directed focusing, and effective long-distance signal transmission are all made possible by the parabolic form. Both on satellites and at satellite ground stations, parabolic antennas are often used.

Bandwidth in satellite communication refers to the range of frequencies allocated for transmitting signals. The type of antenna used influences the available bandwidth and, consequently, the capacity of the communication link [22]. Higher frequency bands generally offer larger bandwidths and can support higher data rates. Different frequency bands are allocated for various satellite communication applications, such as C-band, Ku-band, and Ka-band, each with its unique characteristics and advantages.

The choice of frequency band and antenna type in satellite communication is often a trade-off between factors like signal propagation characteristics, atmospheric absorption, and regulatory considerations [11]. For example, lower frequency bands, such as C-band, are less affected by atmospheric absorption but may require larger antennas. Larger bandwidths and faster data rates may be supported by higher frequency bands, such as Ka-band, although they are more vulnerable to atmospheric attenuation.

1.2 Types of Antennas

There are various types of antennas, each designed for specific applications and operating characteristics. Here are some common types of antennas:

1.2.1 Dipole Antenna

A dipole antenna is one of the most fundamental and widely used types of antennas in radio frequency (RF) communication systems. It's a simple yet effective design that consists of two conductive elements, typically metal rods or wires, oriented parallel to each other and separated by a small gap. When connected to a transmitter or receiver, the dipole antenna efficiently radiates or receives electromagnetic waves [18].

The key principle behind the dipole antenna's operation is the generation of an oscillating electric field between its two elements. When an alternating current flows through the antenna, it creates this oscillating electric field [18]. As a result, electromagnetic waves are generated and propagate outward from the antenna into space. Conversely, when electromagnetic waves impinge upon the antenna, they induce an alternating current in its elements, which can then be detected by the receiver.

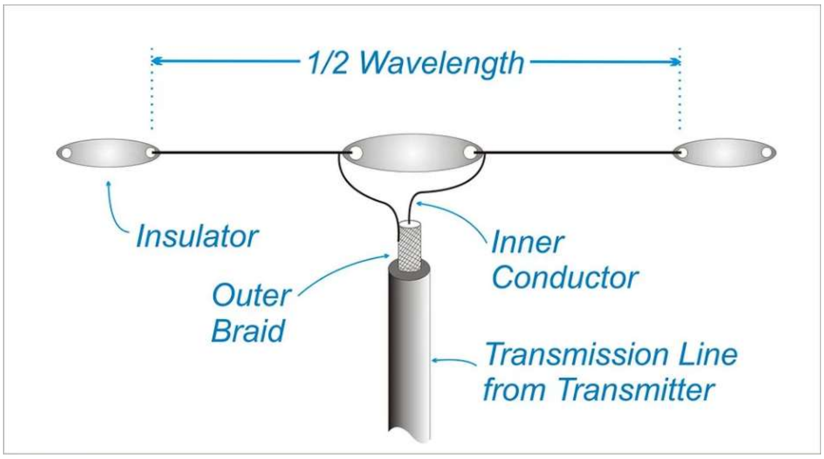


Fig.1.2.1: Dipole Antenna

One of the defining characteristics of a dipole antenna is its resonance. At a specific frequency determined by the length of the elements, the antenna exhibits maximum efficiency in radiating or receiving electromagnetic waves [18]. This resonant frequency is typically half the wavelength of the electromagnetic waves the antenna is designed to operate with. For example, a dipole antenna designed for the 2.4 GHz Wi-Fi band would have a resonant frequency of around 2.4 GHz.

Due to its versatility, dipole antennas may be constructed for low-frequency radio waves as well as microwave wavelengths utilised in satellite communications and radar systems. They are often used in a wide range of applications, such as radio broadcasting, RFID (Radio Frequency Identification), amateur radio, and wireless communication systems [18].

Despite being simple devices, dipole antennas have many disadvantages. Their fundamentally directed character is shown by the fact that their maximum emission occurs perpendicular to the elements' axis. This suggests that the orientation of the transmitter or receiver may have an impact on how effective they are [18]. Dipole antennas' very narrow bandwidth makes them less suitable for applications requiring coverage across a wide range of frequencies than certain other kinds of antennas.

1.2.2 Yagi-Uda Antenna

Radio communication and broadcasting often employ the Yagi antenna, sometimes called the Yagi-Uda antenna, which is an extremely effective directional antenna design. It was developed in 1926 by Japanese engineers Shintaro Uda and Hidetsugu Yagi [18]. Well-known for its simple construction, high gain, and directional characteristics, the Yagi-Uda antenna is ideal for point-to-point communication and for rejecting weak signals coming from one direction while absorbing interference from another [18].

Fig.1.2.2: Yagi-Uda Antenna

A Yagi-Uda antenna is made up of many components that are organised in a certain manner. Usually, it consists of many director elements, one reflector element, and one driven element. The reflector and direction components assist in focusing and directing the radiation pattern, while the driving element, which is coupled to the transmitter or receiver, produces the electromagnetic waves [18].

For a given frequency or range of frequencies, the elements' lengths and spacing are precisely determined to obtain optimum performance [18]. The reflector element is marginally longer than the driven element, while the director elements are somewhat shorter. The elements' "mutual coupling" is produced by this configuration, which improves the antenna's overall gain and directionality.

The high gain of the Yagi-Uda antenna, which is attained by concentrating the radiation pattern in a particular direction, is one of its main benefits. Because of this, it is especially helpful for long-distance communication, which calls for the transmission and reception of signals across large distances. Furthermore, the directional properties of the Yagi-Uda antenna reduce interference from undesired signals, increasing signal-to-noise ratio [18].

Yagi-Uda antennas are widely used in many different applications, such as point-to-point communication systems, amateur radio, Wi-Fi networks, and television and radio transmission. They are available in a variety of sizes and combinations based on the particular needs of the application. The Yagi-Uda antenna is still a popular option despite advancements in antenna technology because of its dependability, simplicity, and efficacy in a variety of communication applications.

1.2.3 Patch Antenna

A typical low-profile radio antenna used in wireless communication systems, including RFID tags, satellite communication systems, and Wi-Fi routers, is the patch antenna [8]. It is a well-liked option for many applications where space is at a premium or when a low-profile antenna is preferred due to its small size, ease of use, and affordable price.

A patch antenna's fundamental component is a flat, metallic radiator or patch that is usually installed over a ground plane that serves as a reflector. The patch is often attached to a feed line that transmits radio frequency (RF) signals to and from the antenna and is composed of conductive materials like copper or aluminium [8]. The antenna's performance characteristics and operating frequency are mostly dependent on the patch's size and the distance between it and the ground plane.

One of the main benefits of patch antennas is their ease of fabrication utilising printed circuit board (PCB) technology, which enables very accurate and consistent mass manufacturing [8]. They may thus be integrated into a variety of electrical systems and gadgets at a reasonable cost.

Because of its directional emission pattern, patch antennas are able to transmit and receive radio frequencies more efficiently in certain directions than others. When targeted signal transmission or reception is required, like in point-to-point communication lines or satellite communication systems, this directional aspect may be helpful [8].

Additionally, patch antennas are adaptable to a variety of communication standards and protocols because they may be made to function at certain frequencies throughout a broad range of the electromagnetic spectrum. Engineers may modify the antenna structure's size and other characteristics to customise its performance to match the demands of certain applications.

1.2.4 Patch Array Antenna

The patch array antenna is one kind of antenna arrangement that is often used in wireless communication, radar, and satellite systems. Their high gain and focused radiation patterns make them suitable for applications needing concentrated transmission or reception [17].

Essentially, a patch array antenna is composed of several individual patch antennas arranged in a grid. Since each patch antenna serves as a radiating element, when they are arranged in an array, they may provide the right radiation pattern. The individual patch antennas are often linked to a feeding network that provides phase and amplitude control in order to steer the beam in a certain direction [17].

One of the main benefits of patch array antennas is their capacity to provide high gain and directivity with a relatively small profile. They might thus be included into compact installations or gadgets. Patch array antennas also provide beam steering flexibility, which allows for dynamic change of the radiation pattern in response to changing communication needs or environmental conditions.

Patch array antennas may be designed to operate at a range of frequencies, from millimetre-wave bands to microwave frequencies, depending on the requirements of the specific application [17]. Their capacity to support many polarisation schemes, including dual, circular, and linear polarisation, further increases their versatility in a variety of communication scenarios.

Patch array antennas are often constructed utilising printed circuit board (PCB) technology because it enables affordable mass manufacture and personalisation. Researchers are also looking at new production techniques like additive manufacturing and integrated antenna-in-package solutions to improve the performance and integration capabilities of patch array antennas [17].

Patch array antennas provide a reliable solution for achieving high-gain directed radiation patterns in wireless communication systems. Because of their adaptability, compact size, and compatibility with several frequency bands, they are a popular choice for applications ranging from mobile communication networks to radar systems and satellite communication terminals. As technology develops, patch array antennas are expected to play an increasingly important role in providing stable, fast wireless connectivity in a range of environments.

1.2.5 Horn Antenna

An antenna used for transmitting and receiving electromagnetic waves, especially in the microwave frequency range, is a horn antenna. The term comes from the form of its flared entrance, which is a common element in its design. Because of its special design, electromagnetic waves can be sent and received efficiently with little loss or distortion [13].

A horn antenna's basic working theory is based on the emission and propagation of electromagnetic waves. An electromagnetic wave changes in properties as it comes into contact with the horn antenna's aperture. The electromagnetic waves are efficiently guided and directed by the horn's flared form, which concentrates them in one direction [13].

The strong directivity and gain that horn antennas can provide is one of its main advantages. Gain is a measurement of an antenna's capacity to amplify signals in a particular direction, while directivity is the antenna's ability to concentrate its radiation pattern in that direction [13]. This is made possible by the horn's flared form, which lowers signal leakage and boosts antenna efficiency.

Applications for horn antennas may be found in radio astronomy, satellite communication, radar systems, and telecommunications. Horn antennas are often employed in communications for point-to-point connections, since long-distance transmission requires great gain and directivity [13]. Horn antennas are essential to radar systems because they send and receive radar signals, which allows for the detection of objects in the surrounding area.

The bandwidth capacities of horn antennas are an additional crucial feature. Horn antennas are a good choice for applications that need a wide range of frequencies because of its flared shape, which provides a large operational bandwidth. Aside from their performance attributes, horn antennas are also rather inexpensive when compared to other antenna types with comparable capacities and have a simpler construction. Because of this, they are a desirable option in many real-world situations where cost, simplicity, and performance are crucial considerations [13].

With its great performance, broad bandwidth, and simplicity of installation, horn antennas are a flexible and effective option for a variety of microwave-frequency communication and sensing systems.

1.3 Basics Antenna Parameters

Antenna parameters are fundamental characteristics that describe the performance and behavior of antennas in electromagnetic wave transmission and reception. These parameters are essential for understanding and designing antennas for various applications. Here are some of the basic antenna parameters:

1.3.1 Radiation Pattern

An antenna's radiation pattern explains the distribution of electromagnetic energy in space during signal transmission or reception [6]. It displays the relative intensity and direction of radiation in three dimensions, illuminating the directional characteristics of the antenna. Determining the coverage area, directivity, and performance parameters of the antenna requires an understanding of the radiation pattern.

Azimuth angle (horizontal plane) and elevation angle (vertical plane) are shown visually on one axis when representing radiation patterns in two dimensions. A map of radiation intensity or power density as a function of angle may be used to visualise the radiation pattern [6].

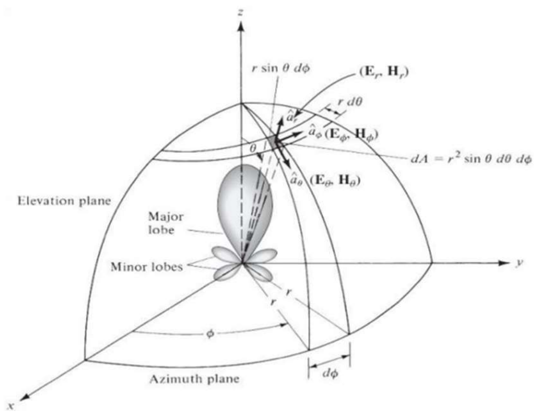


Fig.1.3.1: Radiation Pattern in 3D-Plane of an antenna

A perfect sphere represents the radiation pattern of an isotropic radiator, which is a hypothetical antenna with uniform radiation in all directions. Nonetheless, the majority of useful antennas have directional properties, which lead to angle-dependent radiation patterns.

The main features of radiation patterns include:

1. **Main Lobe**: The main lobe is the primary region of strong radiation, typically centred on the antenna's boresight direction. It represents the primary direction in which the antenna radiates or receives electromagnetic energy [6].
2. **Side Lobes**: Side lobes are regions of radiation that occur away from the main lobe. They represent secondary directions of radiation, usually at lower intensity compared to the main lobe. Side lobes can result from imperfections in antenna design or non-idealities in the antenna structure [6].
3. **Back Lobe**: The back lobe is a region of radiation that occurs opposite the main lobe direction. It represents radiation emitted in the opposite direction to the intended radiation pattern [6]. Minimizing back lobe radiation is important for maximizing antenna directivity and efficiency.
4. **Beamwidth**: The major lobe's angular extent is described by the radiation pattern's beamwidth. It is typically measured between points where the radiation intensity drops to half (−3 dB) of the maximum value. Narrow beamwidth indicates high directivity, while wider beamwidth provides broader coverage but lower directivity.

Radiation patterns vary depending on the antenna's design, operating frequency, and physical characteristics [6]. By analyzing the radiation pattern, engineers can optimize antenna performance for specific applications, such as maximizing coverage area, achieving desired directivity, or minimizing interference with other nearby antennas.

1.3.2 Efficiency

The efficiency with which an antenna transforms input power into electromagnetic energy that is emitted is known as antenna efficiency [6]. In relation to the total input power given to the antenna, it defines the percentage of the input power that is emitted as electromagnetic waves. Antenna efficiency considers a number of parameters, such as conductor losses, dielectric losses, and mismatch losses, that have an impact on energy loss inside the antenna construction.

The formula to calculate antenna efficiency ($\eta\eta$) is given by:

$$\eta = \frac{P_{rad}}{P_{in}} \text{x } 100\%$$

Where:

- P_{rad} is the radiated power, which represents the power that is emitted as electromagnetic waves and propagates away from the antenna.
- P_{in} is the total input power supplied to the antenna.

Antenna efficiency is usually expressed as a percentage, with higher values indicating better performance [6].

The far-field radiation pattern of the antenna, which offers details on the dispersion of radiated energy in space, is often used to compute Prad, the radiated power. The total radiated power is obtained by integrating the power density throughout the whole radiation pattern.

Similar to this, depending on the input voltage and current at the antenna terminals and accounting for any losses in the transmission line or feeding network, PIN, or total input power, may be measured or computed.

Since efficiency directly affects the antenna's performance attributes, including radiation pattern, gain, and directivity, it is a crucial design element [6]. Antenna efficiency optimisation is crucial for maximising system performance, reducing power consumption, and guaranteeing dependable communication across a range of applications, such as mobile devices, radar systems, wireless networks, and satellite communication [6]. Engineers may create antennas that fulfil the needs of certain applications while maximising energy economy and performance by comprehending and optimising antenna efficiency.

1.3.3 Radiation Intensity

A crucial factor in describing the dispersion of electromagnetic energy sent into space surrounding an antenna is radiation intensity. In relation to the antenna, it characterises the power density per unit solid angle in a certain direction [7]. Analysing antenna performance, which includes determining the antenna's directivity, gain, and radiation pattern, requires an understanding of radiation intensity.

The radiation intensity (UU) at a specific point in space and in a particular direction relative to the antenna is given by the formula:

$$U(\theta,\phi)=\frac{P_{rad}(\theta,\phi)}{4\pi}$$

Where:

- $P_{\mathrm{rad}}(\theta,\phi)$ is the radiated power in the direction specified by the azimuth angle (θ) and the elevation angle (ϕ).
- 4π is the total solid angle (in steradians) encompassing the entire space around the antenna.

The radiation intensity is often normalized by dividing by the total radiated power (Prad$P$rad) to yield the power density per unit solid angle.

Radiation intensity is typically plotted as a function of azimuth and elevation angles to visualize the antenna's radiation pattern in three-dimensional space. By analyzing the radiation intensity pattern, engineers can assess various antenna characteristics, such as the directionality of radiation, the extent of side lobes, and the overall shape of the radiation pattern [7].

In practice, radiation intensity is often measured experimentally using specialized equipment such as antenna measurement chambers or antenna pattern measurement systems. These observations support theoretical expectations and provide insightful information about the antenna's performance.

For antenna design, optimisation, and performance assessment in a variety of applications, such as wireless networks, radar systems, satellite communication, and telecommunications, an understanding of radiation intensity is crucial [7]. Engineers may customise antenna designs to fit individual needs and achieve desired performance characteristics by analysing and optimising radiation intensity patterns.

1.3.4 Directivity

An antenna's capacity to concentrate electromagnetic radiation in a particular direction with respect to an idealised isotropic radiator is measured by a basic property called directivity. It calculates the ratio between the average radiation intensity in all directions and the radiation intensity in the target direction. For the purpose of evaluating an antenna's effectiveness in applications that call for focused signal transmission or reception, directivity offers important information into the directional characteristics of the antenna.

Mathematically, directivity (DD) is defined as:

$$D = \frac{4\pi \cdot \text{Maximum Radiation Intensity}}{\text{Total Radiated Power}}$$

Where:

- 4π represents the total solid angle (in steradians) encompassing the entire space around the antenna.
- Maximum Radiation Intensity is the highest radiation intensity observed in the direction of maximum radiation.
- Total Radiated Power is the total power radiated by the antenna in all directions.

Decibels (dB) or a dimensionless ratio are common ways to describe directivity. More radiation concentration in the intended direction is indicated by a higher directivity rating, which boosts antenna gain and strengthens the signal in that direction. Radiation pattern, gain, and other antenna characteristics are intimately correlated with directivity. Directivity focuses exclusively on the directional properties of the radiation pattern, while gain measures the ratio of the power emitted in a given direction to the power radiated by an isotropic radiator under the same circumstances.

In systems where precise control over the directionality of the signal is essential, such as point-to-point communication lines, radar systems, and satellite communication, high directivity antennas are often utilised [7]. By improving antenna design variables such as shape, size, and feed mechanism, engineers may achieve the desired application-specific antenna directivity while maximising signal power and coverage area. across order to achieve reliable and efficient communication across a range of wireless systems, it is essential to comprehend and optimise antenna directivity. Targeted signal transmission and reception are also essential for maximising network performance and minimising interference.

1.3.5 Return loss

Return loss is a fundamental statistic used to quantify the amount of power reflected back from an antenna or other RF component due to impedance mismatch. The

ratio of the incident signal power to the reflected signal power is expressed in decibels (dB) [7]. Return loss is a crucial factor to take into account when assessing the efficiency and performance of antennas, transmission lines, and other RF systems.
The formula to calculate return loss ($RLRL$) is given by:

$RL = 10 \cdot \log_{10}(P_{incident} / P_{reflected})$

Where:

- $P_{incident}$ is the power of the incident signal, which is the power supplied to the antenna or RF component.
- $P_{reflected}$ is the power of the reflected signal, which is the power that returns back due to impedance mismatch.

Return loss is typically expressed in decibels (dB), with higher values indicating lower levels of reflection and better impedance matching. A higher return loss value corresponds to less power being reflected back and more power being absorbed or transmitted by the antenna or RF system.

Return loss and the standing wave ratio (SWR), a crucial metric that defines impedance matching, are intimately associated. The ratio of the standing wave's highest amplitude to its smallest amplitude along the transmission line is known as the SWR. Lower SWR values are correlated with higher return loss values, suggesting improved impedance matching and less signal reflection [7].

Because it directly affects antenna performance, efficiency, and overall system dependability, return loss is a crucial design element. For reducing signal loss, maximising power transmission, and enhancing system performance in a variety of applications, such as satellite communication, wireless networks, telecommunications, and radar systems, high return loss values are preferred.

Return loss measurements are a useful tool for engineers to evaluate antenna performance, identify problems with impedance matching, and optimise system design parameters to get desired performance characteristics [7]. Engineers may improve the efficiency and dependability of radio frequency (RF) systems and guarantee the best possible signal transmission and reception in a variety of communication contexts by comprehending and optimising return loss.

1.3.6 Gain

The antenna gain shows how well an antenna can concentrate radiation in a particular direction as compared to an isotropic radiator, which radiates equally in all directions. When compared to an isotropic radiator operating under identical conditions, it evaluates the amount of power that the antenna can direct in a certain direction [7]. Gain is often expressed in decibels (dB). To calculate gain (G), use this formula:

$$G = 10 \cdot \log_{10}(P_{out}/P_{in})$$

Where P_{out} is the power radiated in the desired direction, and P_{in} is the input power supplied to the antenna.

1.3.7 Bandwidth

The range of frequencies that an antenna may successfully operate across and yet fulfil predetermined performance standards is referred to as its bandwidth. It is often described as the frequency range in which the radiation pattern, gain, and impedance matching of the antenna satisfy certain predetermined specifications [7]. An antenna with a larger bandwidth may function over a larger frequency range. A bandwidth specification is often given as an exact frequency range or as a percentage of the Centre frequency.

1.3.8 VSWR

An antenna's voltage-standby-power ratio, or VSWR, indicates how well it matches the impedance of the transmission line or system to which it is connected [7]. It calculates the connection between the highest and lowest voltages and currents in the transmission line. To calculate VSWR, use the following formula:

$$VSWR = V\mathrm{max}/V\mathrm{min}$$

Where Vmax is the maximum voltage along the transmission line, and Vmin is the minimum voltage. VSWR values indicate the degree of impedance mismatch: lower values (close to 1) indicate better impedance matching, while higher values indicate greater mismatch. A VSWR of 1 represents perfect impedance matching, while higher values indicate increasing levels of mismatch [7].

CHAPTER- 2
MICROSTRIP ANTENNA

An antenna known as a microstrip antenna is made up of a ground plane on one side of a dielectric substrate and a radiating patch or metallic element on the other [16]. It is renowned for being small, having a low profile, and being simple to integrate with contemporary electrical systems. Microstrip antennas are becoming more and more common in many different applications because of their performance and adaptability.

2.1 Evolution of Microstrip Antenna

The development of microstrip antennas can be traced back to the 1950s and 1960s, with early designs focusing on improving the impedance bandwidth and radiation patterns. The breakthrough came in the 1970s when researchers started exploring the potential of microstrip antennas for practical applications [20]. The miniaturization of electronic components and advancements in fabrication technologies contributed to the evolution of microstrip antennas.

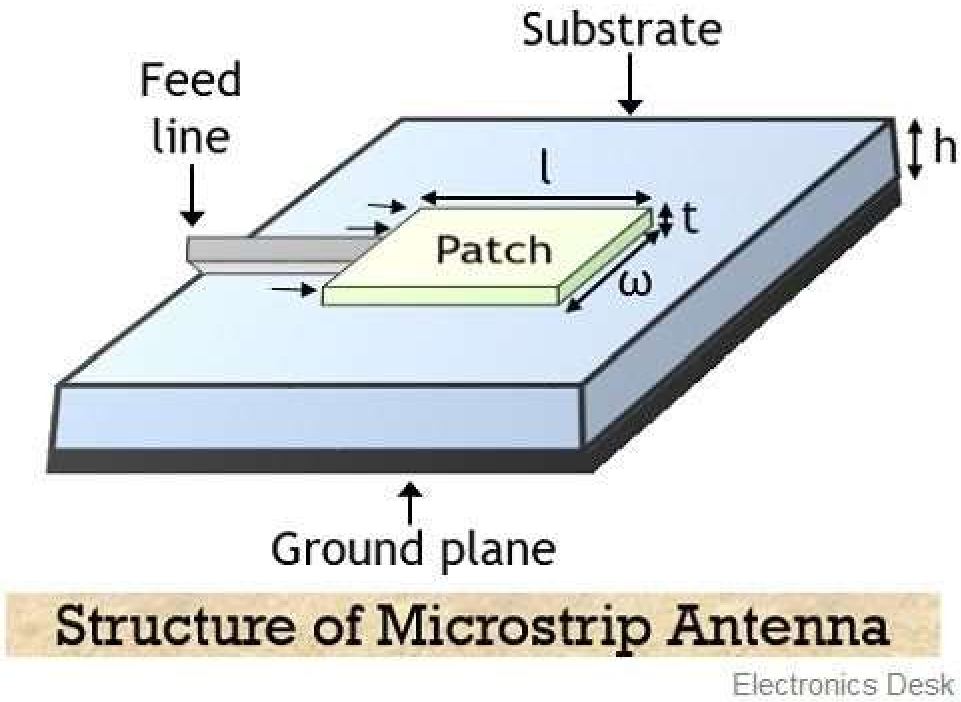


Fig.2.1: Structure of Microstrip Antenna

Over the years, researchers refined the design techniques, materials, and feeding mechanisms, leading to improvements in performance metrics such as bandwidth, gain, and efficiency [20]. The evolution of microstrip antennas also saw the development of various configurations, including rectangular, circular, and patch array designs, each tailored to specific requirements.

With the advent of computer-aided design tools and simulation techniques, engineers could optimize microstrip antenna designs more effectively, allowing for precise control over the antenna's electrical characteristics. This evolution led to the integration of microstrip antennas into diverse applications, including communication systems, satellite links, radar systems, and wireless devices [20].

2.3 Benefits of Microstrip Antennas

1. **Compact Size:** Due to its inherent low-profile and compact design, microstrip antennas are appropriate for space-constrained applications including satellites, mobile devices, and small communication systems [21].
2. **Ease of Integration:** Printed circuit boards (PCBs) may readily include microstrip antennas, allowing for smooth integration with other electrical components. For applications needing a high degree of integration and miniaturisation, this makes them the ideal option.
3. **Low Cost:** Microstrip antenna manufacture is very inexpensive, particularly when done on printed circuit boards (PCBs). Their extensive use in several commercial applications may be attributed in part to their cost-effectiveness.
4. **Wide Frequency Range:** A broad variety of frequencies, from millimeter-wave bands to microwave frequencies, may be accommodated in the construction of microstrip antennas [21]. They may be used in a variety of frequency bands and communication systems because to their adaptability.
5. **Directional Control:** Because microstrip antennas may exhibit directed radiation patterns, focused signal transmission or reception is feasible. This directional control is useful for applications such as point-to-point communication and radar systems.
6. **Lightweight:** Because of their planar shape, microstrip antennas are usually lightweight, which makes them appropriate for uses in where weight is a crucial consideration, including in satellite and aeronautical systems.

Developments in design methodologies, materials science, and manufacturing technologies have characterised the evolution of microstrip antennas. Microstrip antennas have been widely adopted in a variety of applications across the field of modern wireless communication and electronic systems due to their advantages, which include their compact size, ease of integration, low cost, wide frequency range, directional control, and lightweight nature.

2.3.1 Factors affecting the performance of Antenna

- **Substrate Material:** The performance of a microstrip antenna is highly dependent on the material used for the dielectric substrate. The impedance bandwidth, efficiency, and radiation properties of the antenna are affected by the dielectric constant, loss tangent, and substrate thickness.
- **Patch Shape and Size:** The microstrip antenna's resonance frequency, bandwidth, and radiation pattern are all significantly influenced by the size and form of its radiating patch. Achieving the required performance requires optimising these settings.
- **Ground Plane Size and Shape:** The radiation pattern and impedance matching of the antenna are influenced by the ground plane located below the microstrip patch. The efficiency and radiating properties of the antenna may be affected by the size, shape, and closeness of the ground plane to adjacent structures.
- **Feeding Technique:** The radiation pattern, bandwidth, and impedance matching of the microstrip antenna may all be impacted by the feeding technique, which might include proximity coupling or coaxial feeding. Sufficient nutrition is essential to reaching peak performance.
- **Frequency of Operation:** The microstrip antenna's design characteristics are influenced by the operating frequency. For best results, the resonant frequency must coincide with the intended operating frequency.
- **Radiation Pattern Requirements:** The omnidirectional, directional, or other radiation pattern requirements of a given application impact the microstrip antenna's design decisions. These specifications are addressed by modifying the antenna's shape and feeding method.
- **Environmental Factors:** The environment in which the microstrip antenna

operates, including temperature, humidity, and surrounding structures, can impact its performance. Changes in environmental conditions may affect the dielectric properties of the substrate and alter the antenna's characteristics.

- **Polarization:** Microstrip antennas can be designed for different polarization types (e.g., linear, circular). The choice of polarization depends on the specific requirements of the application, and improper polarization alignment can lead to reduced performance.
- **Proximity to Other Objects:** The presence of nearby objects or conductive surfaces can alter the radiation pattern and impedance matching of the microstrip antenna. Proper isolation and placement considerations are crucial to avoid performance degradation.
- **Fabrication Tolerances:** Variations in the fabrication process, such as manufacturing tolerances and material inconsistencies, can impact the performance of microstrip antennas. Careful attention to fabrication details is necessary for maintaining consistent performance across production units.
- **Frequency Band:** Different microstrip antenna designs are suitable for specific frequency bands. The choice of frequency band, whether UHF, VHF, microwave, or millimetre-wave, affects the antenna's size, substrate requirements, and overall performance characteristics.

2.3.2 Construction and Working of Antenna

1. **Substrate:** A dielectric substrate, usually composed of materials like fibreglass, ceramic, or Teflon, is the first component of a microstrip patch antenna. The dielectric constant and loss tangent of the antenna are influenced by the substrate material selection [23].
2. **Ground Plane:** On one side of the substrate, a conductive ground plane is positioned. This forms the antenna's bottom layer and may be either a metal plate or a layer of conductive material, often copper [23]. The antenna's reference point and radiation characteristics are influenced by the ground plane.
3. **Radiating Patch:** A metal patch is placed on the opposite side of the substrate. The antenna's radiating element is this metal patch. The antenna's resonance frequency, bandwidth, and radiation properties are determined by the form and

size of this patch [23].

4. **Feed Line:** A feed line connects the radiating patch to the transmission line or feed network. The feed line can be a microstrip transmission line, coaxial cable, or other suitable structures. The feeding technique influences the impedance matching and overall performance of the antenna.
5. **Dielectric Superstrate (Optional):** In some designs, an additional dielectric layer, known as a superstrate, may be added above the radiating patch. This layer can alter the antenna's radiation pattern and impedance matching.

2.3.3 Working of Microstrip Patch Antenna

1. **Excitation and Feed Mechanism:** The microstrip patch antenna is excited by applying an alternating current (AC) to the feed point [23]. This can be accomplished through a variety of feed mechanisms, such as coaxial feeding, microstrip line feeding, or proximity coupling.
2. **Radiation of Electromagnetic Waves:** An oscillating electric field is produced at the radiating patch when the AC is supplied [23]. Electromagnetic waves are produced as a consequence of the electric field's interaction with the conductive patch.
3. **Resonance and Standing Waves:** The radiating patch's size are selected such that they will resonate at a certain frequency or frequencies. Standing waves are created on the patch surface as a result of this resonance, which raises the radiation efficiency [23].
4. **Ground Plane and Radiation Pattern:** The conductive ground plane functions as a reflector underneath the substrate, influencing the emission pattern of the antenna. The interaction between the radiating patch and the ground plane determines the direction and characteristics of the emitted waves.
5. **Dielectric Substrate Effects:** The effective electrical length of the antenna is influenced by the dielectric substrate's impact on the electromagnetic waves' velocity. The substrate's dielectric characteristics affect the antenna's bandwidth and impedance matching.
6. **Adjustments for Performance:** The dimensions of the radiating patch, the type of feeding mechanism, and other design parameters are adjusted to achieve the

desired resonant frequency, bandwidth, and radiation pattern [23]. Computer-aided design tools and simulation techniques are often employed to optimize these parameters.

Microstrip antennas operate on the principle of radiating electromagnetic waves through a conductive patch on a dielectric substrate. The basic design comprises of a ground plane on one side of a dielectric substrate and a radiating patch, usually composed of copper, on the other. Electromagnetic waves are released when an alternating current is supplied to the radiating patch via a feed mechanism, creating an oscillating electric field [23].

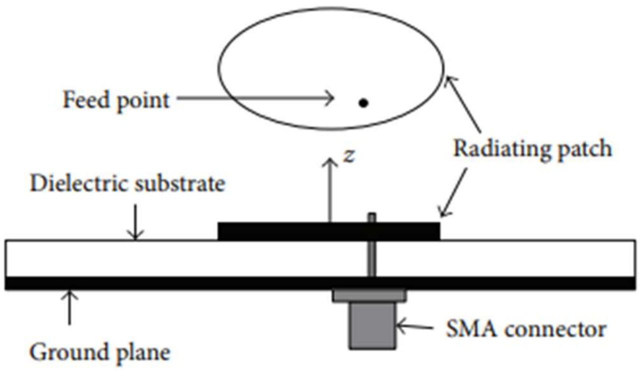


Fig.2.3.3: Side view of EMPA structure with feed arrangement

The radiation pattern of the antenna is affected by the ground plane, which serves as a reflector underneath the substrate. The substrate's dielectric characteristics affect wave velocity and, in turn, the antenna's effective electrical length, which affects bandwidth and impedance matching [23]. The small size, low profile, and simplicity of integration of microstrip antennas into many electrical systems make them well-known.

Microstrip antennas find applications across a diverse range of fields due to their versatility. Common applications include communication systems, satellite links, radar systems, wireless devices, and more. Their compact and lightweight nature makes them particularly suitable for space-constrained environments, such as in mobile devices, where they are commonly used for wireless communication. In satellite communication, microstrip antennas are deployed on both ground-based stations and satellites due to their directional control and high gain. In radar systems, the low profile and ease of fabrication of microstrip antennas make them suitable for phased-array configurations, enabling precise beam steering.

Designing microstrip antennas involves various configurations, and one common type is the rectangular patch antenna. A rectangular metal patch on a dielectric substrate makes up this design, and a feed line connects the patch to the transmission line. Important design factors include the feeding mechanism, substrate material, and patch size [23]. To get desirable properties like resonance frequency, bandwidth, and radiation pattern, these parameters are optimised. Rectangular patch antennas are often used in applications that need moderate performance, simplicity, and ease of integration. They are also rather simple to construct. It is noteworthy, although, that a number of different designs—including stacked patches, circular patches, and array configurations—address particular application demands and demonstrate the versatility of microstrip antennas in meeting a range of communication requirements.

Basic Principles of Operation

- The concept of operation for microstrip patch antennas involves the emission of electromagnetic waves via a conductive patch situated on a dielectric substrate [23].
- Electromagnetic waves are produced when an alternating current is supplied to the patch via a feed mechanism, which causes an electric field to oscillate.
- The antenna's radiation pattern is influenced by the ground plane, which functions as a reflector underneath the substrate [23].
- The dielectric characteristics of the substrate affect the electromagnetic wave velocity, which in turn affects the antenna's effective electrical length, bandwidth, and impedance matching.
- The antenna's resonance frequency, bandwidth, and radiation properties are determined by crucial design factors such as the feeding mechanism, substrate material selection, and radiating patch size.
- Microstrip patch antennas are very adaptable to a broad variety of current communication applications due to their small size, low profile, and simplicity of integration into different electronic systems [23].

CHAPTER- 3
FEEDING TECHNIQUES IN PATCH ANTENNA

Feeding in patch antennas plays a crucial role in determining their performance characteristics, including impedance matching, radiation pattern, polarization, and bandwidth [19]. The feeding technique refers to how the radio frequency (RF) signal is introduced into the patch antenna structure. Various feeding methods have been developed to achieve specific design goals and optimize antenna performance. Let's delve deeper into the different feeding techniques used in patch antennas:

1. **Microstrip Line Feed**: One of the most popular feeding methods for patch antennas is the microstrip line feed. This technique involves sending radiofrequency energy from the external source to the radiating patch element via a microstrip transmission line [19]. The RF signal is linked to the patch by a tiny slot or aperture, and the transmission line is normally attached to the edge of the patch antenna substrate. Microstrip line feeding has a number of benefits, including as compatibility with printed circuit board (PCB) production processes, simplicity of design, and ease of integration. But notably at higher frequencies, it could have problems with impedance mismatch, which would result in reflection losses and decreased antenna efficiency [19].
2. **Coaxial Feed**: The coaxial feed involves connecting a coaxial cable directly to the patch antenna, usually at the center of the radiating element [19]. This feeding technique provides a low-loss and high-impedance match, resulting in improved antenna performance in terms of efficiency and bandwidth. Coaxial feeding is particularly suitable for patch antennas operating at higher frequencies, where precise impedance matching is critical. However, it may require additional design considerations to minimize RF leakage and maintain the integrity of the coaxial connection.
3. **Aperture Coupled Feed**: Aperture coupling is a popular feeding technique for patch antennas, especially for achieving circular polarisation. In this arrangement, the RF signal is linked to the patch element via a microstrip line or coaxial feed through a small hole in the ground plane underneath the patch. Aperture coupling has many advantages, including improved impedance matching, reduced radiation losses, and increased polarisation purity [19]. It allows for more design flexibility

and optimises antenna performance parameters. However, careful planning as well as aperture size and position optimisation are required to get the desired results.

4. **Proximity Coupled Feed**: Proximity coupling involves placing a feeding element, such as a microstrip line or coaxial probe, close to the radiating patch element without direct physical contact [19]. The RF energy is coupled capacitively or inductively from the feeding element to the patch, allowing for efficient energy transfer. Proximity coupling offers advantages such as reduced spurious radiation, improved isolation, and ease of integration into compact antenna designs. It is commonly used in dual-band and multi-band patch antennas to achieve frequency reconfigurability and enhanced performance.
5. **Inset Fed Patch**: In inset feeding, a small portion of the radiating patch element is directly connected to the feed line, typically using a microstrip or coplanar waveguide (CPW) structure. This feeding technique allows for precise control of the antenna impedance and radiation characteristics by adjusting the inset length and width [19]. Inset feeding offers advantages such as improved impedance matching, wider bandwidth, and reduced sensitivity to substrate thickness variations. It is commonly used in broadband and dual-polarized patch antennas for wireless communication systems.
6. **Probing Feed**: Probing feed involves inserting a probe or pin into the substrate beneath the patch element to couple the RF energy directly to the radiating structure. The probe can be connected to a microstrip line or coaxial cable, providing a convenient means of feeding the antenna. Probing feeding offers advantages such as simplicity of design, wide bandwidth, and ease of fabrication. It is commonly used in compact patch antennas for applications requiring omnidirectional radiation patterns and broadband performance.
7. **Slot Coupled Feed**: Slot coupling involves creating a narrow slot in the ground plane beneath the patch element and feeding the RF signal through this slot [19]. The slot acts as a resonant structure, coupling energy from the feed line to the radiating patch element. Slot coupling offers advantages such as improved bandwidth, reduced radiation losses, and enhanced isolation between the feed line and the radiating patch. It is commonly used in dual-polarized and phased array

patch antennas for radar and communication systems [19].

In summary, feeding techniques play a critical role in determining the performance characteristics of patch antennas. Each feeding method has its advantages and limitations, and the choice of feeding technique depends on specific design requirements, such as impedance matching, bandwidth, polarization, and radiation pattern. By carefully selecting and optimizing the feeding mechanism, engineers can tailor the antenna design to meet the needs of various wireless communication applications, ranging from mobile devices to satellite systems.

CHAPTER 4
ELLIPTICAL PATCH ANTENNA

4.1 Introduction

A particular kind of microstrip antenna known for its tiny size and oval shape is the elliptical patch antenna. The way it works is based on the ideas of electromagnetic wave resonance and propagation inside a conductive material patch placed on a dielectric substrate [3]. Numerous benefits, such as its small size, low profile, and simplicity of construction, make this antenna arrangement ideal for a variety of wireless communication applications.

An elliptical patch antenna is normally constructed using a metallic patch—which is often composed of copper or another conductive material—positioned on top of a dielectric substrate, such Rogers material or FR4. The patch is often etched into an elliptical form, however circular patches and other varieties are also frequently seen. Comparing the elliptical form to other geometries, including rectangular or circular patches, improves radiation properties and impedance matching [3].

The capacity of an elliptical patch antenna to produce radiation with a circular polarization is one of its main characteristics. In wireless communication systems, circular polarization is useful because it provides improved signal reception in dynamic situations where the sending and receiving antennas' orientations may change. Circular polarization may be effectively accomplished by carefully planning the elliptical patch antenna's size and feeding mechanism.

Elliptical patch antennas are used in many different domains, such as RFID (Radio Frequency Identification) systems, wireless networks, GPS systems, and satellite communication [3]. Their low profile and small size make them a popular choice for portable electronics like tablets, smartphones, and wireless sensors. They are especially well suited for satellite communication applications because of their capacity for circular polarisation, which is critical for maintaining a constant signal intensity independent of the satellite's orientation.

Moreover, elliptical patch antennas may be made to function throughout a large frequency range, providing flexibility for applications needing broadband performance. Additionally, they are readily incorporated into array topologies to improve directivity and gain for radar systems or long-distance communication lines.

In conclusion, elliptical patch antennas provide a versatile, low-profile option with the ability to polarize in a circle for a range of wireless communication uses. Their adaptability, simplicity in production, and broadband capabilities make them a desirable option for contemporary communication infrastructures.

4.2 Benefits of Elliptical Patch Antenna

Elliptical patch antennas are widely used in a variety of applications due to their many advantages over other antenna configurations. The following are some of the main benefits:

1. **Compact Size:** Because of their planar shape, elliptical patch antennas are naturally compact, which makes them ideal for incorporation into tiny devices with limited space [14]. Particularly useful in portable electronics like smartphones, tablets, and wearable technologies is its compactness.
2. **Low Profile:** Elliptical patch antennas are perfect for situations where antenna visibility or protrusion is desired because of their low profile, which makes it simple to integrate them into flat surfaces or buildings. Applications where aerodynamics and aesthetics are crucial, like car antennae or aeroplane randoms, benefit from this capability.
3. **Circular Polarisation:** Elliptical patch antennas are a good way to overcome polarisation mismatch problems in wireless communication systems as they can produce circularly polarised radiation with ease. Because circular polarisation guarantees consistent signal reception irrespective of the receiving antenna's orientation, elliptical patch antennas are appropriate for dynamic and mobile communication situations.
4. **Broadband Performance:** Elliptical patch antennas are capable of operating over a large frequency range when they are designed and optimised for broadband. Because of their adaptability, they may be used in wideband and multi-band

communication systems, which eliminates the need for several antennas and streamlines system design.

5. **Directional Radiation Pattern**: By using elliptical patch antennas, directional radiation patterns with high gain may be created, improving signal coverage in certain directions and facilitating long-distance communication linkages [14]. Applications including satellite communication, radar systems, and point-to-point communication benefit from this directional capacity.
6. **Ease of Fabrication:** Standard printed circuit board (PCB) manufacturing methods, which are affordable and scalable for mass production, may be used to build elliptical patch antennas [14]. Because of its simplicity of construction, antenna designs may be quickly prototyped and customised to satisfy particular application needs.
7. **Frequency Reconfigurability:** Elliptical patch antennas can be dynamically tuned to operate at different frequencies or adapt to changing environmental conditions, enhancing flexibility and versatility in communication systems. These elements can be added to the antenna design through the use of varactor diodes or switchable feed networks.

All things considered, elliptical patch antennas are a desirable option for a variety of wireless communication applications due to their advantages such as their small size, low profile, circular polarisation, broadband performance, directional radiation pattern, simplicity of fabrication, and frequency reconfigurability.

4.3 Gap Coupling in Antenna

Gap coupling in patch antennas refers to the method of coupling energy between two closely spaced patches or resonators to achieve desired antenna characteristics. In the context of patch antennas, gap coupling involves creating a small air or dielectric gap between two patch elements, allowing electromagnetic energy to couple or transfer between them [5].

This coupling mechanism can be utilized to achieve various antenna functionalities, such as impedance matching, bandwidth enhancement, polarization diversity, and beam steering. By adjusting the dimensions of the gap and the distance between the patches, engineers can control the strength and nature of the coupling effect, tailoring the antenna's performance to specific requirements [5].

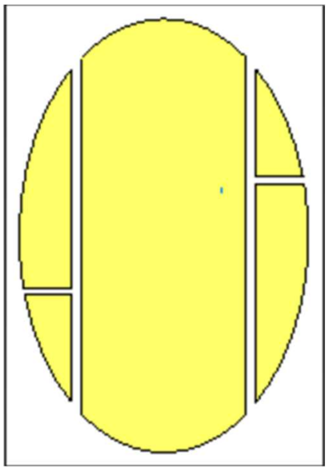


Fig.4.3: Gap-Coupled Patch

Gap-coupled patch antennas are commonly used in applications where compact size, high efficiency, and versatile performance are essential. They find applications in wireless communication systems, radar systems, satellite communication, and other RF (Radio Frequency) and microwave applications [5].

Overall, gap coupling in patch antennas provides a flexible and effective means of achieving desired antenna characteristics, making it a valuable technique in antenna design and optimization.

4.4 Benefits of Gap Coupling

Gap coupling in elliptical patch antennas offers several benefits that enhance their performance and versatility in various applications. These advantages stem from the ability to control and manipulate electromagnetic fields between closely spaced patches, optimizing antenna characteristics to meet specific requirements. Here's an exploration of the benefits of gap coupling in the context of elliptical patch antennas:

1. **Bandwidth Enhancement:** Gap coupling allows for the manipulation of the coupling strength between patches, which can significantly broaden the antenna's operating bandwidth [12]. By adjusting the dimensions of the gap and the distance between patches, engineers can achieve broader frequency coverage, enabling the antenna to operate over a wider range of frequencies. This bandwidth enhancement is particularly advantageous in broadband communication systems,

where the antenna needs to support multiple frequency bands or accommodate frequency shifts due to environmental factors.

2. **Improved Impedance Matching:** Gap coupling facilitates effective impedance matching between the antenna and the feedline or transmission medium. By carefully designing the dimensions and geometry of the coupling gap, engineers can achieve better impedance matching, minimizing signal reflections and maximizing power transfer efficiency [12]. This ensures optimal performance and signal integrity, especially in high-frequency applications where impedance matching is critical for maintaining communication reliability.
3. **Polarization Diversity:** Gap coupling enables the creation of dual-polarized or cross-polarized antenna configurations, enhancing polarization diversity in the antenna system. By coupling two orthogonal patches with a carefully designed gap, the antenna can radiate or receive electromagnetic waves with different polarization orientations simultaneously [12]. This polarization diversity improves the antenna's resilience to signal fading and polarization mismatch, enhancing communication reliability in diverse propagation environments.
4. **Compact Design:** Elliptical patch antennas with gap coupling can achieve compact and low-profile designs without compromising performance. The ability to couple energy between closely spaced patches allows for the integration of multiple antenna elements within a limited physical space. This compactness is advantageous in applications where size and form factor constraints are paramount, such as mobile devices, IoT sensors, and unmanned aerial vehicles (UAVs), enabling the deployment of high-performance antennas in space-constrained environments.
5. **High Gain and Directivity:** Gap-coupled elliptical patch antennas can exhibit higher gain and directivity compared to single-patch configurations. By coupling multiple patches with optimized spacing and geometry, engineers can achieve constructive interference and radiation pattern shaping, resulting in increased signal strength and directionality in desired directions [5]. This high gain and directivity are beneficial for long-range communication, satellite links, and point-to-point communication systems requiring focused signal transmission or reception.

6. **Frequency Agility:** Gap coupling provides flexibility in tuning the antenna's resonant frequency and adjusting its operational frequency range. Engineers can fine-tune the coupling parameters to achieve desired frequency responses, enabling the antenna to adapt to changing frequency requirements or mitigate interference from neighbouring frequency bands [5]. This frequency agility enhances the antenna's versatility and suitability for multi-band or frequency-agile communication systems.

In summary, gap coupling in elliptical patch antennas offers a multitude of benefits, including bandwidth enhancement, improved impedance matching, polarization diversity, compact design, high gain and directivity, and frequency agility. These advantages make gap-coupled elliptical patch antennas well-suited for a wide range of applications, from wireless communication networks and satellite systems to IoT devices and beyond, where reliable and efficient antenna performance is essential.

CHAPTER 5
SOFTWARE USED

The CST Studio package is a powerful software package for simulating and enhancing electromagnetic systems and devices. Numerous electromagnetic simulation tools, including multiphysics analysis, optimisation, and 3D electromagnetic field simulation, are available in the CST Studio Suite, which was developed by CST - Computer Simulation Technology, a branch of Dassault Systèmes [10].

One of the main aspects of the CST Studio Suite is its electromagnetic simulation capabilities, which enable engineers to investigate complex electromagnetic processes and interactions within devices and systems [10]. The suite supports several simulation techniques, including the method of moments (MoM), finite integration technique (FIT), and finite element method (FEM), which makes it easier to accurately and efficiently simulate electromagnetic fields over a wide range of frequencies and sizes.

Engineers may create accurate and comprehensive virtual prototypes of their ideas with the aid of the comprehensive modelling and meshing tools and user-friendly interface of the CST Studio Suite [10]. The simplicity with which users may import CAD models, select material characteristics, and set up simulation scenarios facilitates the modelling of complex geometries and structures.

In addition to electromagnetic modelling, the CST Studio Suite has multiphysics tools that let engineers investigate the connections between electromagnetic fields and other physical phenomena including fluid flow, mechanical stress, and temperature effects. This integrated approach allows for a complete study and system and device optimisation by accounting for the interplay between several physical domains.

The CST Studio Suite, which also includes advanced optimisation algorithms and design exploration tools, may assist engineers maximise device performance, save development time, and save costs [10]. By using these optimisation tools, engineers may explore various design alternatives, modify parameters, and improve device performance—all while keeping objectives and design constraints in mind.

All things considered, the CST Studio package is a powerful and versatile software package for electromagnetic modelling and optimization that finds widespread use in a variety of industries, such as telecommunications, electronics, automotive, and aerospace. Its Multiphysics analysis, user-friendly interface, and wide range of capabilities may be of significant use to engineers designing and refining electromagnetic systems and apparatuses.

5.1 Features of CST

CST Studio Suite offers a comprehensive set of features tailored to meet the needs of engineers and researchers working in electromagnetic simulation and optimization across various industries. Some key features include:

1. **Advanced Simulation Techniques**: CST Studio Suite employs a range of advanced simulation techniques, including finite element method (FEM), finite integration technique (FIT), and method of moments (MoM), providing accurate and efficient electromagnetic field simulation across a wide frequency spectrum [26].

2. **Multiphysics Analysis**: The software enables multiphysics simulations, allowing users to analyze the interactions between electromagnetic fields and other physical phenomena such as thermal effects, mechanical stress, and fluid flow. This integrated approach provides insights into the complex behavior of devices and systems.

3. **User-Friendly Interface**: CST Studio Suite features an intuitive user interface with powerful modeling and meshing tools, facilitating the creation of detailed virtual prototypes [26]. Users can import CAD models, define material properties, and set up simulation scenarios easily, streamlining the modeling process.

4. **High-Performance Computing (HPC) Support**: The software offers support for high-performance computing (HPC), allowing users to leverage parallel processing and distributed computing capabilities for faster simulation times and increased efficiency.

5. **Optimization and Design Exploration**: CST Studio Suite includes advanced optimization algorithms and design exploration tools, enabling users to optimize device performance, explore design alternatives, and improve efficiency while considering design constraints and objectives [26].

6. **Versatile Applications**: With its wide range of features and capabilities, CST Studio Suite is suitable for various applications, including antenna design, microwave circuits, RF components, EMC/EMI analysis, and photonics.

Overall, CST Studio Suite provides a powerful platform for electromagnetic simulation and optimization, empowering users to design, analyze, and optimize electromagnetic systems and devices with confidence and efficiency.

CHAPTER 6
LITERATURE REVIEW

Kretzschmar's seminal work in "Wave propagation in hollow conducting elliptical waveguides," published in the IEEE Transactions on Microwave Theory and Techniques in 1970, laid foundational groundwork for understanding electromagnetic wave behavior in elliptical waveguides. The study investigated the characteristics of wave propagation within hollow conducting elliptical waveguides, which are essential components in microwave and RF systems. By examining the theoretical framework and experimental results, Kretzschmar elucidated the fundamental principles governing wave propagation, including mode structure, dispersion characteristics, and impedance properties, specific to elliptical waveguides. The research contributed valuable insights into the design, analysis, and optimization of waveguide-based communication and sensing systems, offering practical guidance for engineers and researchers in the field. Kretzschmar's work serves as a cornerstone in the literature on waveguide theory and microwave engineering, providing a comprehensive understanding of electromagnetic wave behavior in elliptical geometries. The findings presented in the paper have been referenced extensively in subsequent research and have informed the development of advanced waveguide-based technologies, highlighting its enduring relevance and impact in the field of microwave engineering.

The paper by C. Y. Huang and W. C. Hsia titled "Planar elliptical antenna for ultrawideband communications," published in Electronics Letters in 2005, contributes to the literature on ultrawideband (UWB) antennas. The study focuses on the design and analysis of a planar elliptical antenna specifically tailored for UWB communications, which require antennas capable of transmitting and receiving signals across a wide frequency range. The research addresses the growing demand for UWB antennas capable of supporting high-speed data transmission, ranging from short-range wireless personal area networks (WPANs) to radar and imaging applications. By utilizing an elliptical geometry, the authors aim to achieve broadband performance while maintaining a compact and planar form factor suitable for integration into modern communication systems. The paper likely discusses the design methodology, simulation techniques, and experimental validation of the proposed elliptical antenna's performance characteristics, such as impedance matching, radiation pattern, and gain across the UWB frequency spectrum. Additionally, the study may compare the proposed antenna's performance with existing UWB antenna designs, highlighting its advantages and limitations in terms of bandwidth, efficiency, and practical implementation. Overall, the paper contributes valuable insights into the design and optimization of planar elliptical antennas for UWB communications, offering potential solutions to meet the demanding requirements of modern wireless communication systems.

The study conducted by H. Jung and C. Seo in 2002 presents an analysis of elliptical microstrip patch antennas with a focus on considering the attachment mode. This research contributes to the understanding of the behavior and performance of elliptical patch antennas, particularly concerning how they are attached or mounted. The paper likely discusses the impact of different attachment methods on antenna characteristics such as impedance matching, radiation pattern, and bandwidth. By examining various attachment modes, the authors aim to identify the most effective attachment technique for optimizing antenna performance. This study adds to the existing body of literature on microstrip patch antennas by offering insights into the influence of attachment mode, an aspect that may have practical implications for antenna design and implementation. Understanding how the attachment method affects antenna performance is crucial for engineers and researchers striving to develop efficient and reliable antenna systems for diverse applications. Furthermore, the research published in IEEE Transactions on Antennas and Propagation reflects the significance of the topic within the field of antenna engineering, indicating its relevance and potential impact on advancing antenna design methodologies and techniques.

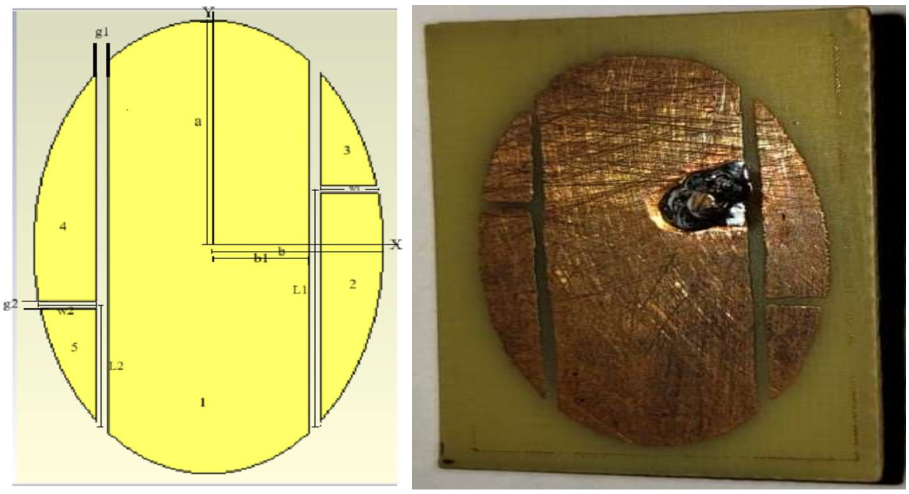
The paper by D. Bhardwaj et al. titled "Design and analysis of a gap coupled split circular patch with elliptical slot filled with elliptical patch," published in the Indian Journal of Radio and Space Physics in 2010, contributes to the literature on innovative antenna design and analysis techniques. The study focuses on the development and evaluation of a novel antenna configuration involving a gap-coupled split circular patch with an elliptical slot filled with an elliptical patch. This research adds to the existing body of literature by introducing a unique approach to antenna design, leveraging the concept of gap coupling and incorporating intricate geometrical features such as split circular patches and elliptical slots. By exploring this novel antenna architecture, the authors aim to enhance antenna performance in terms of bandwidth, impedance matching, and radiation characteristics. The paper underscores the importance of gap coupling as a mechanism for improving antenna performance and highlights the potential of complex geometries, such as elliptical slots and patches, in achieving desired antenna characteristics. The findings of this study contribute valuable insights to the field of antenna engineering, offering new perspectives on design methodologies and optimization techniques for next-generation wireless communication systems.

The study conducted by Sharma et al. (2011) explores the design and implementation of a broadband gap-coupled assembly of patches forming an elliptical patch antenna. The research investigates the performance and characteristics of the antenna configuration, focusing on its broadband capabilities and effectiveness in wireless communication applications. The literature review provides context by discussing previous studies and advancements in patch antenna design, particularly those utilizing gap coupling techniques. The authors highlight the significance of broadband antennas in modern communication systems, emphasizing the growing demand for antennas capable of supporting multiple frequency bands and accommodating diverse communication protocols. Previous research in the field of patch antennas and gap coupling is reviewed to establish the foundation for the study. This includes discussions on various coupling techniques, such as proximity coupling and aperture coupling, and their implications for antenna performance. Additionally, the literature review may cover relevant theoretical frameworks, simulation methodologies, and experimental approaches employed in previous studies to analyze and optimize patch antenna configurations. Through the literature review, Sharma et al. (2011) aim to identify gaps in existing research and justify the need for their proposed broadband gap-coupled elliptical patch antenna. The review serves to contextualize the study within the broader landscape of antenna design and highlight its potential contributions to the field.

CHAPTER 7
ANTENNA DESIGN AND RESULTS

7.1 Basic Elliptical Patch Antenna

The CST Studio Suite 2023 software was used to create the microstrip antenna. The substrate is made of FR-4 material, with a thickness of 1.6 mm and εr=4.3. Figure 8 depicts the patch antenna's design. where an elliptical form with precise proportions is etched out of the substrate. To maximise radiation, the ground and patch are made of the same material—copper. Coaxial feeding is the mechanism used to excite the antenna. The frequency at which the antenna is intended to resonate is 5.23 GHz. The operating frequency is used to determine the dimensions of the whole patch and ground. The height and epsilon value of the substrate are calculated using the following formulas, and the results are shown in Table 1:



(a) (b)

Fig.7.1: (a) View of assembly patches forming gap coupled elliptical patch antenna. (b) Photograph of designed antenna

Serial Number	Design parameter	Values

1.	Dimension of elliptical patch: (i) Semimajor axis (ii) Semi minor axis	“a”=15mm “b”=10mm
2.	Central edge truncated ellipse(1) (i) Length of semimajor axis (ii) Length of semi minor axis after truncation	“a”=“a1”=15mm “b1”=5.7mm
3.	Dimensions of patches (2) and (4)	“L1”=13.3mm, “W1”=3.5mm
4.	Dimensions of patches (3) and (5)	“L2”=9.4mm, “W2”=3.5mm
5.	Width of gaps`	“g1”=7mm, “g2”=5mm

7.2 Observations

7.2.1Return Loss

Return loss is the total of an antenna's or radio frequency (RF) system's capacity to transport power from the transmitter to the antenna and the quantity of that power that is reflected back due to impedance mismatches. It is often expressed in decibels (dB) and represents the ratio of power incident on the antenna to power reflected back.

Return loss (RL) is calculated using the following formula:

$RL\ (dB) = -20 \cdot \log10(P_{\text{incident}}/P_{\text{reflected}})$

S11, also known as return loss, is a measurement of the power reflected from the antenna. At the resonance frequency, it ought to be very tiny. Figure illustrates the suggested antenna design's return loss. It is evident that the suggested patch antenna resonates at two different frequencies: 5.23 GHz and 7.34 GHz. The return losses at these frequencies, with the reference set at -10 dB, are -44.09 dB and -39.19 dB, respectively. These results are rather good for the current broadband communication issue.

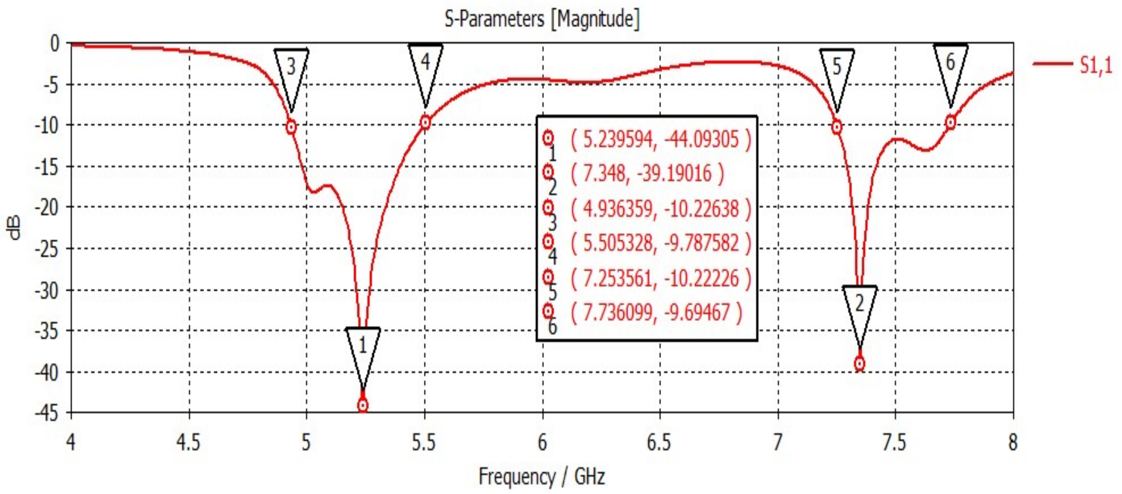


Fig.7.2.1: S-parameter for the elliptical patch antenna

Return loss is often the first result to be looked at and recorded since it indicates the range that the antenna will operate across. It measures how much of a signal a transmission line irregularity reflects back to itself. The frequency ranges that we have received are 5.23 GHz and 7.34 GHz, and -10dB is utilised as the reference in this case (as shown in the figure).

7.2.2 VSWR (Voltage Standing Wave Ratio)

The voltage standing wave ratio (VSWR), which is often used in radio frequency (RF) systems to quantify the mismatch between the transmission line and the antenna, is another metric that is closely related to return loss [14]. A measure of how well the antenna system fits the transmission line's impedance is the voltage signal to noise ratio, or VSWR.

VSWR is calculated using the following formula:

VSWR= $1-\rho/1+\rho$

Fig. displays the VSWR graph for the elliptical patch antenna at various frequencies.

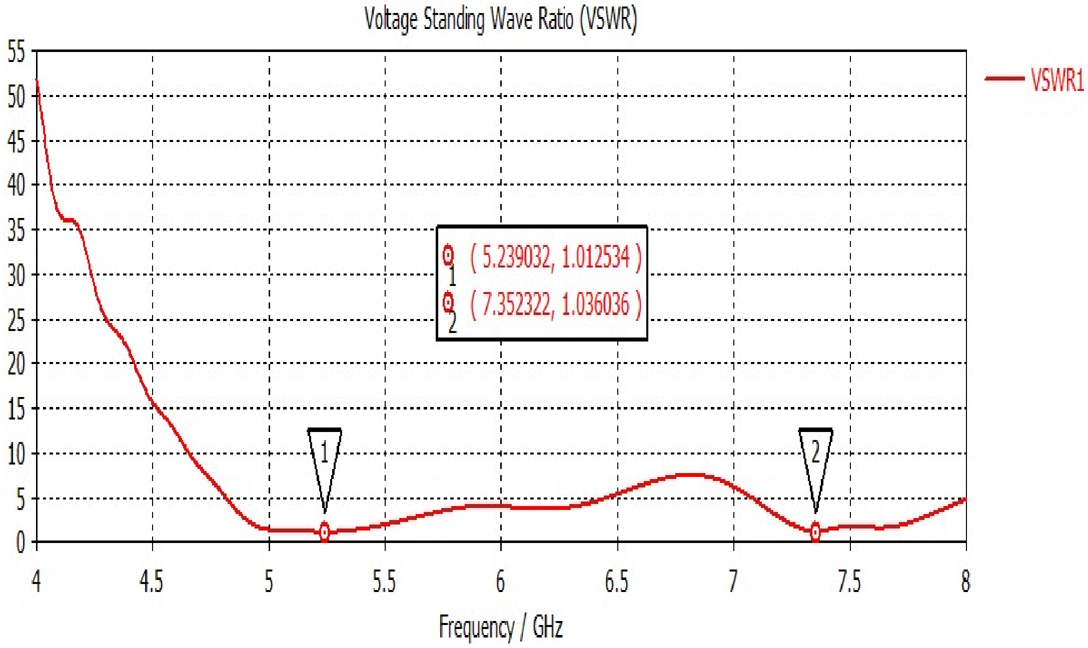


Fig.7.2.2: VSWR graph

Graph shows that the value of VSWR at resonant frequency of 5.23GHz is 1.01 it suggests that our antenna is well designed and tuned to operate efficiently at these frequencies.

7.2.3 Z Parameters

The "Z parameters" in the context of electrical engineering refer to the impedance parameters, also known as the impedance matrix or Z matrix. These parameters are used to characterize the behavior of linear time-invariant electrical networks, such as circuits or systems.

The Z matrix is a square matrix that relates the voltage and current at the input and output ports of a network. The elements Z_{11}, Z_{12}, Z_{21}, and Z_{22} represent the self-impedance and mutual impedance parameters of the network. These parameters provide insights into how the network responds to electrical signals and help in analysing and designing complex electrical systems.

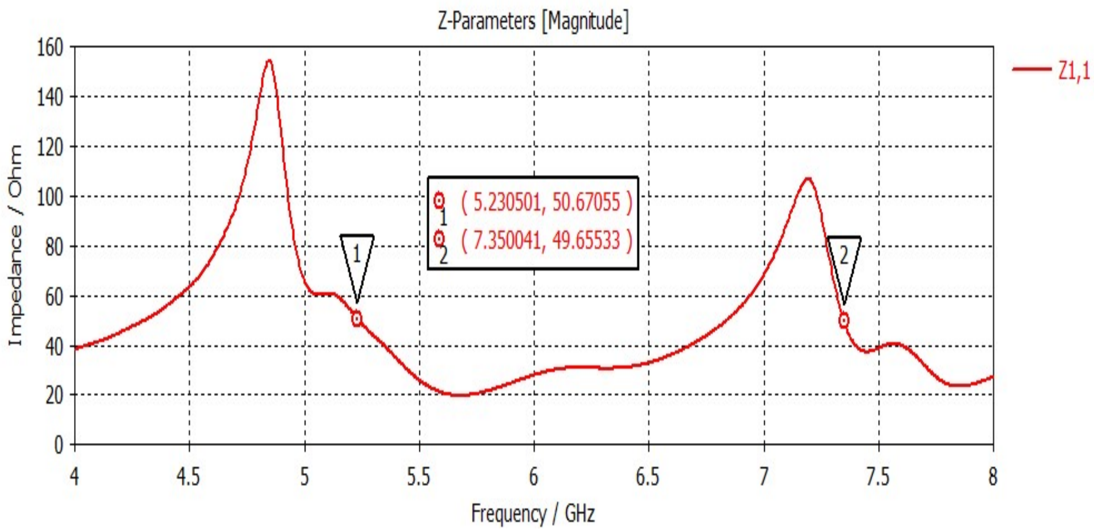


Fig.7.2.3: Z- parameter graph

The impedance values obtained, 50.67 ohms and 49.65 ohms, are relatively close to the standard characteristic impedance of many transmission lines (typically 50 ohms). This suggests that our antenna is reasonably well-matched to the transmission line at both frequencies.

7.2.4 Y Parameters

In the context of antennas, the Y parameters, or admittance parameters, are not as commonly used as other parameter sets like S parameters (scattering parameters). However, in some cases, Y parameters can still be employed to characterize the behavior of antennas, especially in the analysis of impedance matching and antenna network interactions.

The Y parameters in the antenna domain would describe the relationship between the currents and voltages at the input and output terminals of an antenna or an antenna network. These parameters can be useful in understanding how well the antenna is matched to its feeding network, providing insights into the efficiency of power transfer.
In a Y matrix for an antenna system, Y_{11} represents the self-admittance of the antenna, Y_{12} signifies the mutual admittance between antennas or components, and similar terms Y_{21} and Y_{22} describe the self-admittance and mutual admittance of the connected components.

While S parameters are more prevalent in antenna analysis due to their effectiveness in describing signal flow and reflection characteristics, the use of Y parameters in antennas can be valuable when examining the electrical behaviour of the antenna structure and its interactions with the surrounding network.

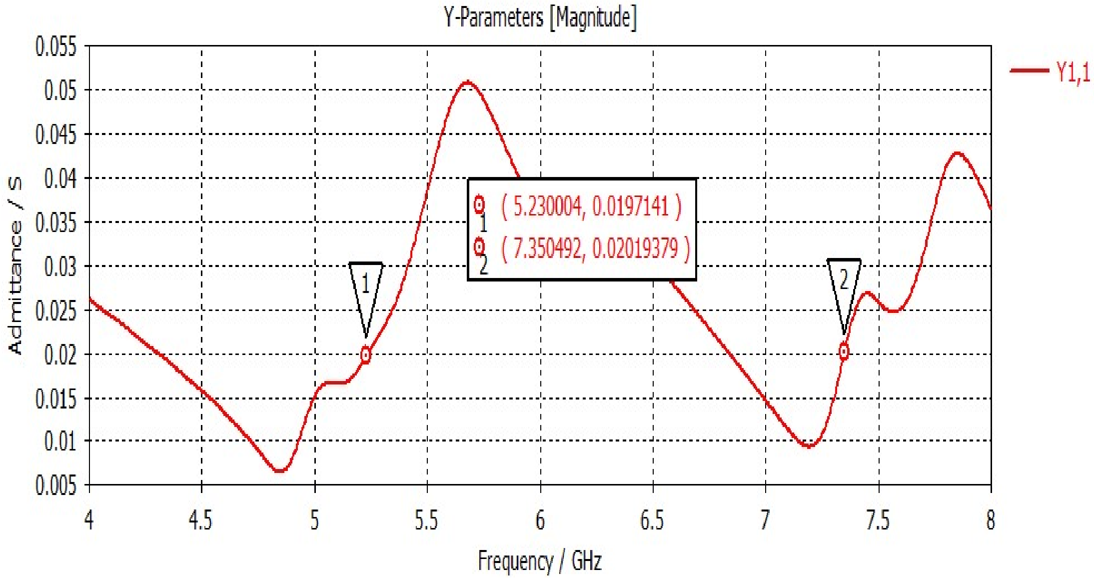


Fig.7.2.4: Y-parameter graph

7.2.5 Directivity

Directivity is a key term in antenna engineering that describes how focused the power radiated in a particular direction. It is the proportion of the radiation intensity in the selected direction to the average radiation intensity in all directions. Directivity, which is often expressed in decibels (dB), is the degree to which an antenna can focus its radiation in a certain direction.

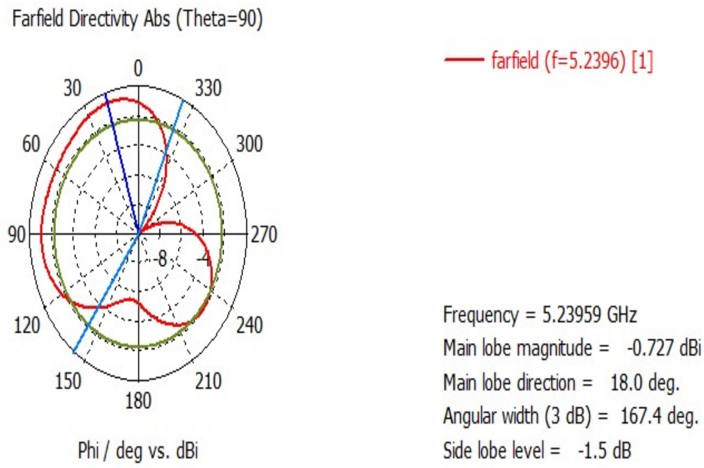


Fig.7.2.5: Directivity of Antenna

7.2.6 Antenna gain

Antenna gain, measured in relation to an isotropic radiator (an idealized point source emitting equally in all directions), is a critical metric that describes an antenna's capacity to concentrate or direct its emitted power in a particular direction. It measures how well an antenna transmits or receives signals in a certain direction and is represented in decibels (dB). Antenna gain takes into account the antenna's efficiency and directivity. Increased sensitivity and a more concentrated radiation pattern in the intended direction are indicated by a greater gain. It's crucial to remember that although gain increases signal strength in one direction, a wider coverage area is often sacrificed in the process. In many applications, such as wireless networks, radar systems, satellite communication, and telecommunications, where maximising signal strength and coverage is crucial, antenna gain is a crucial component. With 5.23GHz as the resonance frequency, we obtained a gain of 4.124dBi.

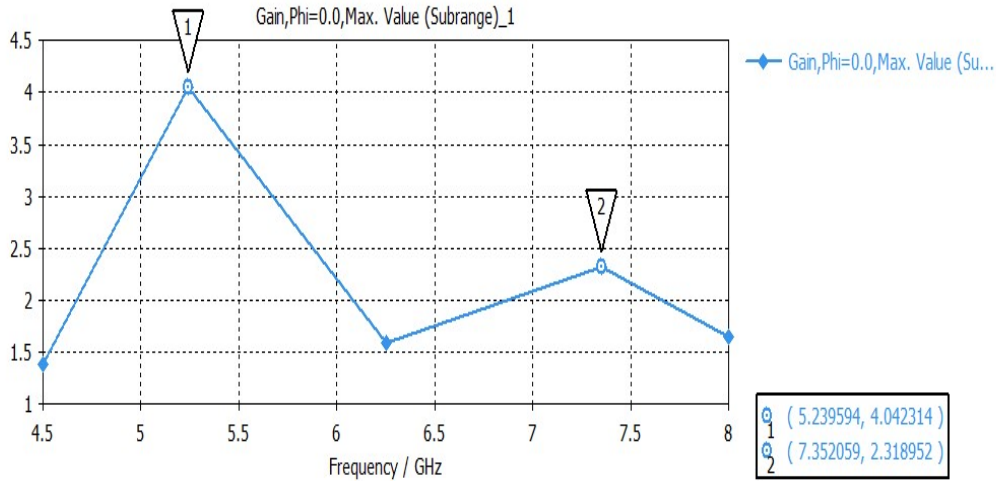


Fig.7.2.6: Gain of antenna

7.2.7 Far Field

The far field of an antenna is the area where the electromagnetic waves that are emitted have a mostly spherical wavefront and are characterised by the existence of in phase, mutually perpendicular electric and magnetic fields. This area is usually positioned considerably further away from the antenna than the antenna itself is in terms of physical size. Accurate and reliable signal propagation is made possible in the far field by the radiation pattern's stability, which is independent of the distance from the antenna. The far-field characteristics of antennas are often examined by engineers and scientists in order to maximise their efficiency, gain, and directivity. For efficient long-range communication and signal reception, antennas are made to work within a certain wavelength range, which is known as the far-field distance.

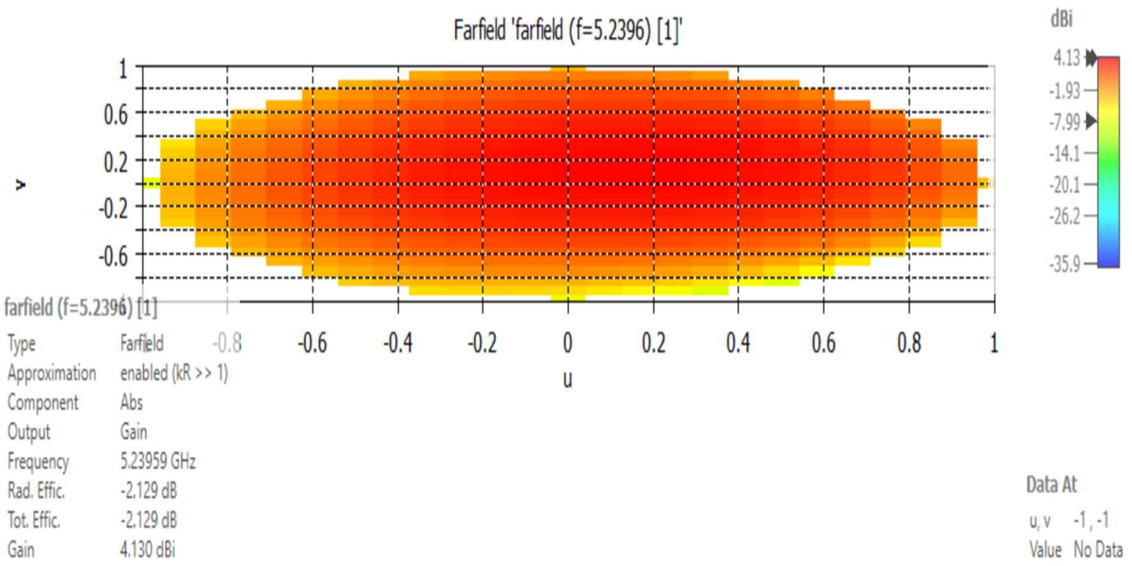


Fig.7.2.7: Far Field 2D

7.2.8 Surface Current Density

The graphic shows the surface current distribution of the mentioned elliptical patch antenna. In this case, the mobility of electrical phenomena on the patch floor is producing the current densities that are causing antenna dissipation.

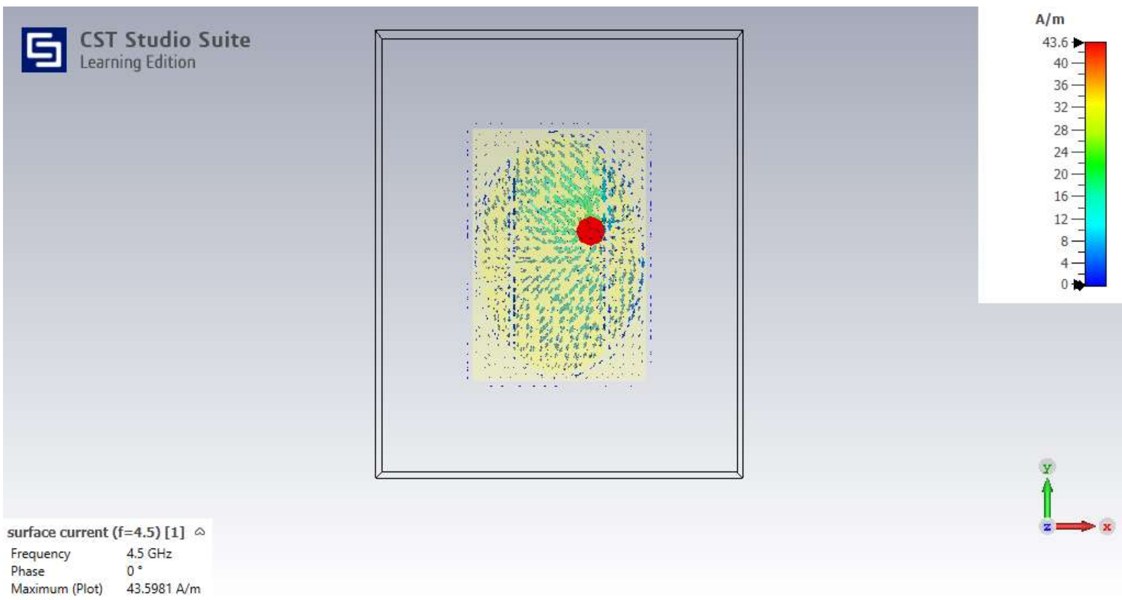


Fig.7.2.8: Discrete port Voltage graph

7.2.9 Discrete Port Parameters

The excitation to the antenna was provided by the port using the coaxial feed which connected the patch body to the edge of the antenna. The parameters (namely, current, voltage, and impedance) at this port is calculated and the following plots are observed:

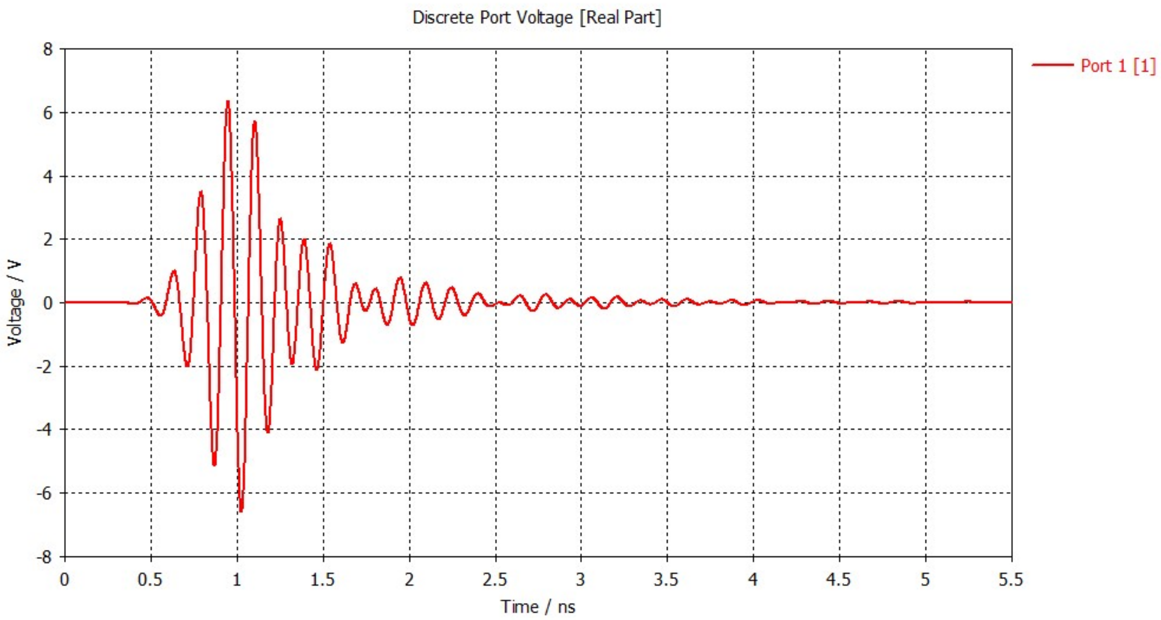


Fig.7.2.9: Discrete port Voltage graph

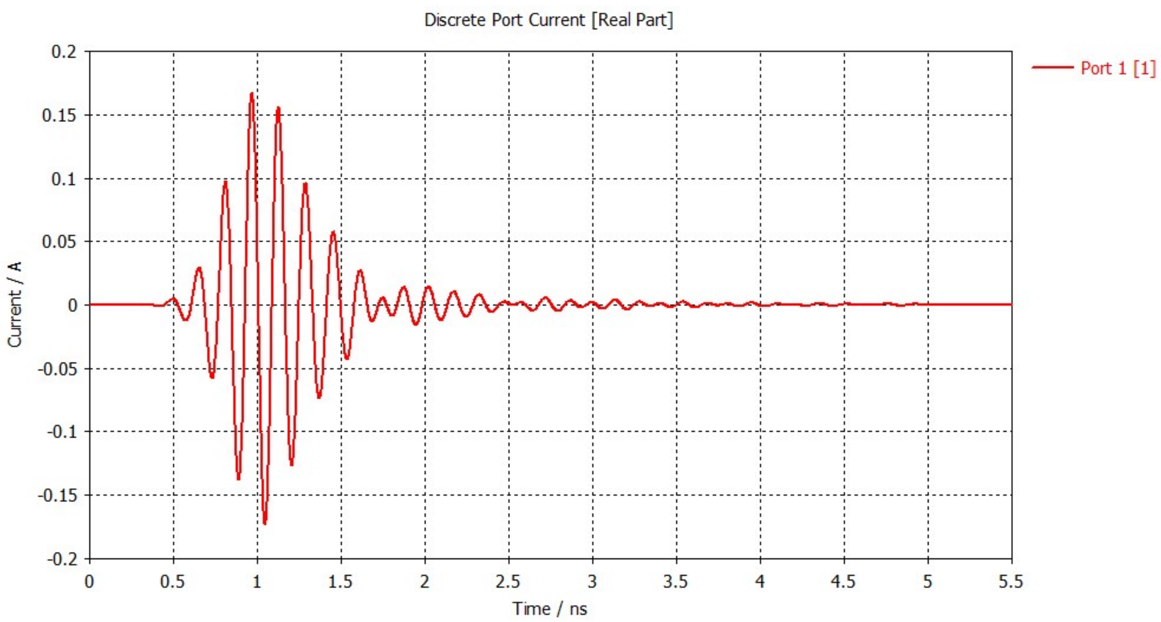


Fig.7.2.10: Discrete port current graph

7.3 Disadvantages

Antennas play a crucial role in wireless communication systems, but they do have some disadvantages and challenges. Here are a few:

1. **Directionality and Beamwidth:** Many antennas have directional characteristics, meaning they focus their energy in specific directions. This can be a disadvantage when trying to establish communication with devices in multiple directions simultaneously [14]. On the other hand, omnidirectional antennas have wider coverage but may have reduced range.
2. **Size:** Antenna size is often determined by the wavelength of the signal it is designed to transmit or receive. In some cases, especially at higher frequencies, the required antenna size may be impractical for certain applications, such as compact electronic devices [14].
3. **Signal Attenuation and Fading:** Antennas are susceptible to signal attenuation, especially in environments with obstacles or signal-absorbing materials [14]. Fading, caused by signal interference or multipath propagation, can degrade the quality of communication.
4. **Interference:** Antennas can be sensitive to interference from other electronic devices, nearby transmitters, or environmental factors. This interference can lead to signal degradation and affect communication reliability.
5. **Complexity:** Designing and implementing efficient antennas often require a good understanding of electromagnetic theory. Achieving optimal performance may involve complex engineering considerations, and incorrect designs can result in poor signal quality.
6. **Frequency Limitations:** Antennas are typically designed for specific frequency ranges. Matching the antenna to the frequency of the signal is crucial for optimal performance. However, this can limit the flexibility of the antenna in handling signals outside its designated frequency range.
7. **Environmental Factors:** Antennas can be affected by environmental conditions such as weather, temperature, and humidity. Adverse weather conditions like rain, snow, or strong winds may impact signal quality and reliability.

Despite these disadvantages, ongoing research and advancements in antenna technology aim to address these challenges and improve overall performance in various applications.

7.4 Applications

A 5.23 GHz elliptical patch antenna has a range of potential applications across various industries due to its frequency compatibility and versatile design. Here are some notable applications:

1. **Wireless Communication Systems**: The 5.23 GHz frequency falls within the Wi-Fi spectrum, making elliptical patch antennas suitable for wireless communication systems. These antennas can be utilized in Wi-Fi routers, access points, and other networking devices to facilitate high-speed data transmission and internet connectivity in homes, offices, and public spaces [14].
2. **Satellite Communication**: Elliptical patch antennas operating at 5.23 GHz can be deployed in satellite communication systems for uplink and downlink applications. They can serve as ground station antennas to establish communication links with satellites in orbit, enabling data transfer, broadcasting, and remote sensing for applications such as weather monitoring, navigation, and telecommunications.
3. **Radar Systems**: Radar systems often operate at microwave frequencies, including 5.23 GHz, for various sensing and detection applications. Elliptical patch antennas can be integrated into radar systems for target detection, tracking, and surveillance in military, aerospace, and automotive applications. They can also be used in traffic monitoring systems and collision avoidance systems.
4. **Remote Sensing and Monitoring**: Elliptical patch antennas can be employed in remote sensing and monitoring applications, such as environmental monitoring, agricultural sensing, and infrastructure monitoring. They can be used to collect and transmit data from sensor nodes deployed in remote or hazardous environments, providing valuable insights for research, resource management, and decision-making.
5. **IoT (Internet of Things)**: The proliferation of IoT devices necessitates compact and efficient antennas for wireless connectivity. Elliptical patch antennas operating at 5.23 GHz can be integrated into IoT devices, smart sensors, and wearable gadgets to enable wireless communication and data exchange. These antennas enable IoT applications such as smart home automation, industrial monitoring, and healthcare systems.

6. **Point-to-Point Communication Links**: Elliptical patch antennas can establish point-to-point communication links between fixed locations, providing reliable and high-speed data transmission over long distances. These links can be used for backhaul connectivity in telecommunications networks, wireless internet service provision, and building-to-building connectivity in urban areas.
7. **Radio Astronomy**: In radio astronomy, 5.23 GHz elliptical patch antennas can be employed as receiving antennas in radio telescopes for astronomical observations and research. They can capture and analyze cosmic microwave background radiation, study galactic structures, and detect celestial phenomena, contributing to our understanding of the universe [14].

Overall, the 5.23 GHz elliptical patch antenna offers versatile applications in wireless communication, satellite communication, radar systems, remote sensing, IoT, point-to-point links, and radio astronomy, making it a valuable technology across diverse industries and research fields. Its compact size, high performance, and frequency compatibility make it suitable for a wide range of applications requiring efficient and reliable wireless connectivity and data transmission.

CHAPTER 8
CONCLUSION

The analysis and evaluation of the elliptical patch antenna, detailed in Chapter 6, provide comprehensive insights into its performance characteristics and potential applications. Developed through meticulous design using CST Studio Suite 2023 software, the antenna showcases remarkable efficiency and versatility in wireless communication systems. Operating at a resonant frequency of 5.23 GHz, it demonstrates impressive return loss values, indicating minimal power reflection and optimal transmission. This resonance at multiple frequencies, including 7.34 GHz, underscores the antenna's adaptability and potential for broadband communication solutions.

In addition to return loss, key parameters such as Voltage Standing Wave Ratio (VSWR), Z parameters, Y parameters, directivity, and antenna gain were thoroughly evaluated to gauge performance across various metrics. The analysis reveals a well-matched impedance profile, with Z parameters closely aligning with the standard characteristic impedance of 50 ohms. This suggests efficient power transfer and minimal signal loss, crucial for maintaining communication reliability and data integrity.

Moreover, directivity measurements highlight the antenna's ability to focus radiation in specific directions, essential for applications requiring targeted signal transmission or reception. With an antenna gain of 4.124 dBi at the resonant frequency, the antenna demonstrates significant signal amplification compared to an isotropic radiator, indicating enhanced sensitivity and effective utilization of transmitted or received signals.

Despite its notable performance, the antenna is not without its challenges. Directionality and beamwidth limitations may restrict simultaneous communication in multiple directions, while size constraints, particularly at higher frequencies, could pose challenges for integration into compact electronic devices. Signal attenuation and interference, common in wireless communication environments, remain inherent challenges that could impact communication reliability and signal quality.

However, despite these challenges, the antenna's applications span a wide range of industries and research domains. From wireless communication systems, including Wi-Fi routers and satellite communication terminals, to radar systems for target detection and surveillance, the antenna finds utility in diverse applications requiring efficient and reliable wireless connectivity. Its deployment in IoT devices, smart sensors, and remote monitoring systems underscores its role in enabling connectivity and data exchange in the era of the Internet of Things (IoT).

Furthermore, its potential in radio astronomy for astronomical observations and celestial phenomena detection highlights its significance in scientific research and exploration. As advancements in antenna technology continue to address challenges such as design complexity and frequency limitations, the antenna's role in facilitating wireless communication and data transmission across various domains is expected to expand further, driving innovations and advancements in communication systems and technologies.

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