COMPACT WEARABLE ANTENNA BASED ON METASURFACES

A Project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC*)
Sangivalasa, bheemili mandal, visakhapatnam dist.(A.P)
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CERTIFICATE

This is to certify that the project report entitled **"COMPACT WEARABLE ANTENNA BASED ON METASURFACES"** submitted by **K.Lasya Sri (319126512023),B.Harshavardhan(319126512010),K.Tarun(319126512029),P.S.Akhil Nakka(319126512041)** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Anil Neerukonda Institute of technology and Sciences(A), Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

This work presents the design of compact wearable antennas using Composite Right-Left Handed Transmission Line (CRLH-TL) metasurfaces for use in Wearable Medical Body-Area Network (WBAN) devices. The metasurface acts as the ground plane for isolation and as the main radiator, and a printed coplanar waveguide (CPW) is used as the feed structure. This design overcomes the narrowband characteristics of microstrip antennas and achieves low Specific Absorption Rate (SAR).

Two antenna geometries are investigated, the first with a size of 39.4×33.4 mm^2 and a resonant frequency of 2.65 GHz, and the second with a size of 55.79×52.25 mm^2, targeting dual-band operation at 2.45 and 3.65 GHz. Both designs exhibit high efficiency and better bandwidth compared to planar monopoles and microstrip antennas. The performance of these designs is also found to be robust to structural deformation and human body loading, making them suitable for WBAN applications.

The simulation of these designs is performed using the CST suite. The proposed antennas are expected to provide reliable wireless communication for WBANs and other medical devices worn on the body. Overall, the use of CRLH-TL metasurfaces provides a promising approach to designing compact and efficient wearable antennas for medical and other applications.

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INTRODUCTION

1.1 Introduction to Antennas

An antenna is a transducer that can convert electromagnetic waves into electrical signals and vice versa. It is designed to operate within a certain frequency band, rejecting signals outside of that band. As antennas are essential components of communication systems, understanding their basics is important. With the increasing demand for compact antennas, many developments have been made to design minimal weight, low profile antennas. Microstrip patch antennas have been a focus of such development due to their design flexibility.

Radiation occurs when there is a time-varying current or acceleration of charge in a conducting wire. The movement of charges creates a magnetic field, and the combination of time-varying electric and magnetic fields generates electromagnetic waves. An antenna can be thought of as a transmission line that creates and radiates electromagnetic waves into free space. The energy associated with an antenna's field patterns changes with distance and can be divided into three regions: the near field, the transition region, and the far field. (Constantine A.Balanis)

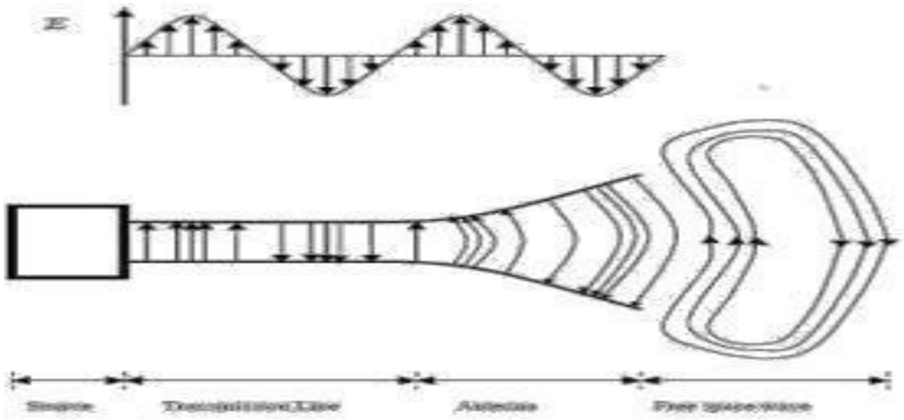


Fig 1.1. Radiation from an antenna

1.2. ANTENNA PARAMETERS

1.2.1. Radiation Pattern:

A radiation pattern is a graphical representation of the relative strength of the radiation emitted by an antenna in different directions. It shows how the antenna radiates electromagnetic energy into space, and how the intensity of that radiation varies with angle.

The radiation pattern is a three-dimensional pattern that is usually represented as a two-dimensional graph, with the antenna at the center and the angle of radiation plotted on the horizontal axis, and the power or intensity of radiation plotted on the vertical axis.

Radiation patterns are important because they help engineers and technicians design and optimize antennas for specific applications. By analyzing the radiation pattern of an antenna, they can determine its gain, directionality, polarization, and other characteristics that affect its performance.

Different types of antennas have different radiation patterns. For example, a dipole antenna typically has a radiation pattern that is strongest in the plane perpendicular to the antenna, while a parabolic dish antenna has a radiation pattern that is strongest in the direction of the dish. The radiation pattern of an antenna can also be affected by the environment in which it is placed, such as the presence of nearby buildings or other structures.

1.2.2. Radiation intensity:

Radiation intensity is a measure of the strength of the radiated electromagnetic waves from an antenna in a particular direction. It is defined as the power radiated per unit solid angle in a specific direction and is expressed in watts per steradian (W/sr).

The radiation intensity is related to the radiation pattern of the antenna and can be calculated using the formula:

U = (Prad * r^2) / (4 * pi)

Where U is the radiation intensity, Prad is the power radiated by the antenna in watts, r is the distance from the antenna in meters, and pi is the mathematical constant approximately equal to 3.14159.

The radiation intensity is a useful parameter in antenna design as it provides information about the directionality and efficiency of the antenna. The directivity of an antenna, which is a measure of the concentration of radiation in a particular direction, is related to the maximum radiation intensity of the antenna.

The radiation intensity can also be used to calculate the total power radiated by an antenna, which is given by the formula:

Prad = (4 * pi * U * D^2) / r^2

Where D is the dimension of the antenna in the direction of maximum radiation, and r is the distance from the antenna. This formula is known as the Friis transmission equation and is used to calculate the power received by a receiving antenna from a transmitting antenna in a communication system.

1.2.3. Gain:

In the context of antenna design and analysis, gain refers to the measure of the directional power output of an antenna compared to that of an ideal isotropic radiator. An isotropic radiator is an ideal antenna that radiates power uniformly in all directions, whereas a real-world antenna may radiate more power in some directions than others.

The gain of an antenna is defined as the ratio of its radiation intensity in a particular direction to that of an ideal isotropic radiator radiating the same total power. It is usually expressed in decibels (dB) and is given by the formula:

Gain (dB) = 10 log (U / Ui)

Where U is the radiation intensity of the antenna in the given direction, and Ui is the radiation intensity of an ideal isotropic radiator.

The gain of an antenna can be measured experimentally using specialized equipment, such as a gain antenna, or it can be calculated using electromagnetic simulation software or analytical models based on the antenna's physical properties.

The gain of an antenna is an important characteristic as it provides information about the directionality and efficiency of the antenna. A high gain antenna is able to radiate more power in a specific direction, making it useful in applications such as long-range communication or radar systems where the antenna needs to focus its power in a specific direction. However, a high gain antenna may also have a narrower radiation pattern, limiting its coverage area.

1.2.4. Directivity:

Directivity is a measure of the ability of an antenna to focus its radiation in a particular direction, relative to an isotropic radiator. It is expressed as a ratio of the radiation intensity in a given direction to the average radiation intensity over all directions.

Directivity is a key parameter in antenna design and analysis, as it provides information about the ability of an antenna to transmit or receive signals in a specific direction. A high directivity antenna can transmit or receive signals with greater efficiency in a particular direction, while minimizing the transmission or reception of signals from unwanted directions.

Directivity is related to the gain of an antenna, but is a more fundamental parameter. While gain is a measure of the efficiency of the antenna in converting electrical power to radiated power in a particular direction, directivity is a measure of the antenna's ability to focus radiation in a particular direction.

Directivity is often expressed as a dimensionless quantity or in dBi (decibels relative to an isotropic radiator), which is a logarithmic measure of directivity referenced to an isotropic radiator. The directivity of an ideal isotropic radiator is 1, and any antenna with a directivity greater than 1 is more directional than an isotropic radiator.

Directivity can be calculated using electromagnetic simulation software or analytical models based on the physical properties of the antenna, such as its size, shape, and radiation pattern. In practical antenna systems, directivity is affected by factors such as the presence of nearby objects, the frequency of operation, and the polarization of the signal.

1.2.5. Return Loss (S_{11}):

Return Loss (S11) is a measure of the reflected power of an antenna or other device, expressed as a ratio in decibels (dB) between the incident power and the reflected power. It is a key parameter in antenna design and analysis, as it provides information about the efficiency of the antenna in transferring power to the transmission line or other load.

Return Loss is defined as the ratio of the power of the reflected wave to the power of the incident wave, expressed in dB. It is often denoted as S11, which is one of the scattering parameters (S-parameters) used to describe the performance of a device. The lower the value of S11, the better the match between the antenna or device and the transmission line or load. A perfect match would result in an S11 value of 0 dB, indicating no reflected power.

Return Loss is typically measured using a Vector Network Analyzer (VNA) or other test equipment that can measure the complex reflection coefficient of the antenna or device. The reflection coefficient is then converted to Return Loss using the following equation:

Return Loss (dB) = $-20 \log(|\Gamma|)$

Where Γ is the reflection coefficient.

Return Loss is an important parameter in antenna design, as it affects the efficiency and performance of the antenna system. High levels of reflected power can cause signal loss, distortion, and other issues, while a good match between the antenna and the transmission line or load can improve performance and reduce losses.

1.2.6. Voltage Standing Wave Ratio:

The Voltage Standing Wave Ratio (VSWR) is a measure of the mismatch between the antenna or transmission line and the load, expressed as a ratio of the maximum voltage to the minimum voltage along the line. It is a key parameter in antenna design and analysis, as it provides information about the efficiency of the antenna in transferring power to the transmission line or other load.

VSWR is defined as the ratio of the maximum voltage to the minimum voltage along a transmission line or antenna, expressed as a ratio or in decibels (dB). It is a measure of how much of the incident power is reflected back towards the source due to the mismatch between the impedance of the antenna or transmission line and the impedance of the load. A perfect match would result in a VSWR value of 1:1 or 0 dB, indicating no reflected power.

VSWR is typically measured using a VSWR meter or other test equipment that can measure the amplitude of the forward and reflected waves on the transmission line or antenna. The VSWR can then be calculated using the following equation:

VSWR = (V_{max} / V_{min})

Where Vmax is the maximum voltage along the line, and Vmin is the minimum voltage along the line.

A high VSWR can cause signal loss, distortion, and other issues, while a good match between the antenna and the transmission line or load can improve performance and reduce losses. VSWR is an important parameter in antenna design, as it affects the efficiency and performance of the antenna system. A VSWR of 2:1 or less is generally considered acceptable in most applications.

1.2.7. Bandwidth:

Bandwidth refers to the range of frequencies over which an antenna or a communication system can operate effectively. It is a measure of the ability of the system to transmit information over a given frequency range.

In the context of antennas, bandwidth is often defined as the frequency range over which the antenna can operate with acceptable performance characteristics, such as acceptable gain, impedance, and radiation pattern. Specifically, it is the difference between the upper and lower frequencies at which the antenna's performance is within a specified range of values. For example, an antenna may have a bandwidth of 100 MHz, meaning it can operate effectively over a frequency range of 900 MHz to 1 GHz.

In the context of communication systems, bandwidth refers to the amount of data that can be transmitted over a communication channel in a given amount of time. It is typically measured in bits per second (bps) or multiples thereof, such as kilobits per second (kbps) or megabits per second (Mbps). A wider bandwidth allows for more data to be transmitted in a given time, which can result in faster data transfer rates and higher quality signals.

Bandwidth is an important consideration in the design of antennas and communication systems, as it affects the ability of the system to operate effectively and efficiently over a given frequency range. It is also a key factor in determining the overall capacity and performance of a communication network.

1.2.8. Antenna Efficiency:

An antenna's ability to convert the electrical power supplied to it into radiated power is known as its efficiency. It is defined as the ratio of the radiated power to the input power, expressed as a percentage.

In practical antennas, some of the input power is lost due to various factors such as ohmic losses in the antenna conductors, dielectric losses in the antenna material, and reflections at the antenna feed point. These losses result in a decrease in the radiated power and therefore reduce the efficiency of the antenna.

The efficiency of an antenna can be measured experimentally using specialized equipment or can be estimated theoretically using mathematical models. Typically, a high-efficiency antenna is desirable as it results in a higher radiated power for a given input power, which translates to a stronger signal and longer communication range.

Antenna efficiency can be affected by various factors, including the antenna design, operating frequency, antenna size, and material properties. It is an important parameter to consider in the design and selection of antennas for different applications, such as wireless communication systems, radar systems, and satellite communication systems.

1.2.9. Beamwidth:

Beamwidth is a measure of the angular width of the main lobe of the radiation pattern of an antenna. It represents the extent of the angular region in which most of the radiated power is concentrated. The beamwidth is typically defined as the angle between the two half-power points (or -3 dB points) of the radiation pattern, which are the points where the radiated power drops to half of the maximum value.

The beamwidth of an antenna depends on the antenna design and operating frequency. In general, a narrower beamwidth implies a more directional antenna, which concentrates the radiated power in a smaller angular region and provides a higher gain in the main lobe direction. Conversely, a wider beamwidth implies a less directional antenna, which radiates power more uniformly in different directions and provides a lower gain in the main lobe direction.

Beamwidth is an important parameter to consider in antenna design and selection for different applications. For example, in radar systems, a narrow beamwidth is desirable as it provides high directional sensitivity and enables detection and tracking of targets at long distances. In wireless communication systems, a wider beamwidth may be preferred to cover a larger area or to accommodate user mobility.

1.3. Types of Antennas

We will now introduce and briefly discuss some forms of the various antenna types in order to get a glance as to what will be encountered in the remainder of the book.

1.3.1. Wire Antennas:

Wire antennas are a type of antennas that use thin wires or conductive elements to radiate or receive electromagnetic waves. They are widely used in various applications such as communication, broadcasting, radar, and navigation systems.

There are several types of wire antennas, including:

Dipole antenna: A dipole antenna consists of two conductive elements of equal length, typically oriented in a straight line and fed at the center. It is one of the simplest and most common types of antennas, and it radiates in a broad pattern perpendicular to its length.

Loop antenna: A loop antenna is a closed-loop of wire, which can be circular, square, or rectangular in shape. It is a highly directional antenna that can be used for receiving weak signals or for direction finding.

Yagi antenna: A Yagi antenna is a directional antenna that consists of a driven element (a dipole or folded dipole), one or more directors (shorter elements in front of the driven element), and one or more reflectors (longer elements behind the driven element). It has high gain and directional sensitivity, and is commonly used for TV and radio reception.

Helical antenna: A helical antenna consists of a coiled wire that is wound into a helix shape. It is a highly directional antenna that can be used for satellite communication, remote sensing, and space applications.

Random wire antenna: A random wire antenna is an unbalanced antenna that uses a long wire or a random length of wire as the radiating element. It is a simple and inexpensive antenna that can be used for shortwave reception, but it requires a matching network to prevent reflections and to achieve a good impedance match with the transmission line.

Wire antennas can be designed and optimized for different frequencies, bandwidths, radiation patterns, and polarization types. They are typically lightweight, easy to install, and can be constructed using simple materials such as copper wire, aluminum tubing, or coaxial cable.

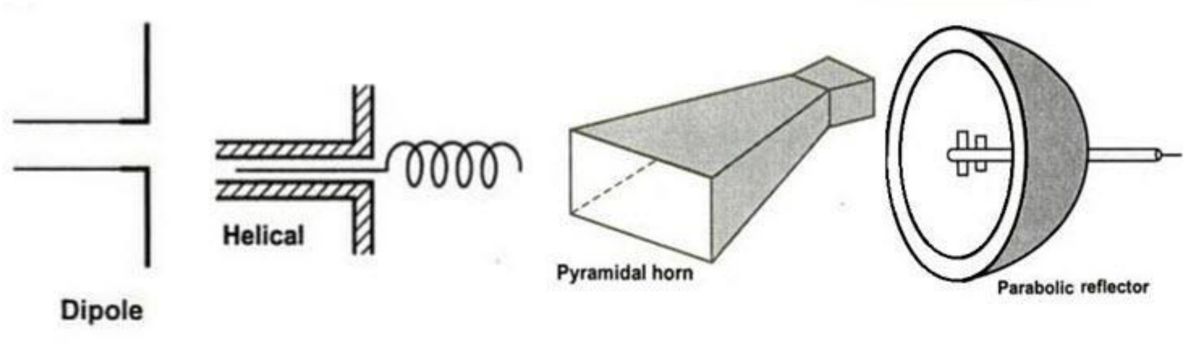


Fig.1.2 Wire Antennas

1.3.2. Aperture Antennas:

Aperture antennas are a type of antenna that use an opening or aperture in a conducting surface to radiate or receive electromagnetic waves. They are typically used in applications that require high gain and directional sensitivity, such as satellite communication, radar, and astronomy.

There are several types of aperture antennas, including:

Horn antenna: A horn antenna is a flared waveguide that tapers from a larger aperture to a smaller aperture. It has high gain and directional sensitivity, and is commonly used for radar and communication systems.

Parabolic reflector antenna: A parabolic reflector antenna uses a curved dish-shaped reflector to focus the incoming or outgoing electromagnetic waves onto a small feed antenna at the focal point. It has high gain and directional sensitivity, and is commonly used for satellite communication and radio astronomy.

Slot antenna: A slot antenna is a narrow aperture cut in a conducting surface, which radiates or receives electromagnetic waves. It can be designed to have a wide bandwidth and can be used for communication and radar systems.

Microstrip antenna: A microstrip antenna is a flat antenna that uses a patch of conductive material on a dielectric substrate to radiate or receive electromagnetic waves. It is low-profile and can be integrated with other electronic components, making it popular for mobile communication and wireless networking applications.

Aperture antennas can be designed and optimized for different frequencies, bandwidths, radiation patterns, and polarization types. They are typically more complex and expensive to manufacture than wire antennas, but they offer higher gain and directional sensitivity.

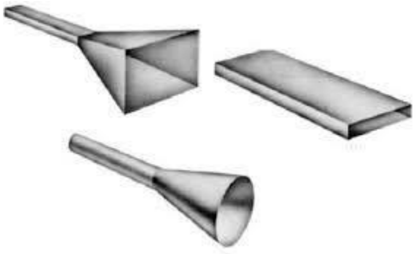


Fig.1.3 Aperture Antennas

1.3.3. Microstrip Antennas:

Microstrip antennas, also known as patch antennas, are a type of antenna that consist of a thin conducting patch placed over a ground plane, with a dielectric substrate sandwiched in between. They are commonly used in applications that require a low-profile, lightweight, and conformal antenna, such as in mobile communication devices, GPS, and wireless networking.

The basic design of a microstrip antenna consists of a rectangular or circular patch of conductive material, such as copper, etched on a thin substrate, such as a printed circuit board. The substrate is usually made of a dielectric material, such as fiberglass or ceramic, which provides support and insulation between the patch and the ground plane. The ground plane is usually a large metal plate, such as copper, that serves as a reflecting surface and provides a low-impedance path for the current.

The size and shape of the patch, as well as the thickness and dielectric constant of the substrate, determine the resonant frequency and radiation characteristics of the antenna.

The patch can be designed to have various shapes, such as rectangular, circular, or triangular, and can be fed using various techniques, such as coaxial probes, microstrip lines, or aperture coupling.

Microstrip antennas offer several advantages over other types of antennas, including:

Low profile: Microstrip antennas are thin and conformal, which makes them suitable for use in compact and space-constrained devices.

Lightweight: Microstrip antennas are made of lightweight materials, which makes them ideal for use in portable and mobile devices.

Low cost: Microstrip antennas are relatively easy and inexpensive to fabricate, as they can be printed on a substrate using standard printed circuit board manufacturing techniques.

Broadband performance: Microstrip antennas can be designed to have a wide bandwidth and can operate over a broad frequency range.

However, microstrip antennas also have some disadvantages, including:

Low efficiency: Microstrip antennas have low radiation efficiency, as a significant amount of the radiated energy is lost through the substrate and ground plane.

Narrow beamwidth: Microstrip antennas have a narrow beamwidth, which makes them suitable for directional applications but limits their coverage area.

Sensitivity to nearby objects: Microstrip antennas are sensitive to nearby objects, such as other electronic components, which can affect their radiation pattern and performance.

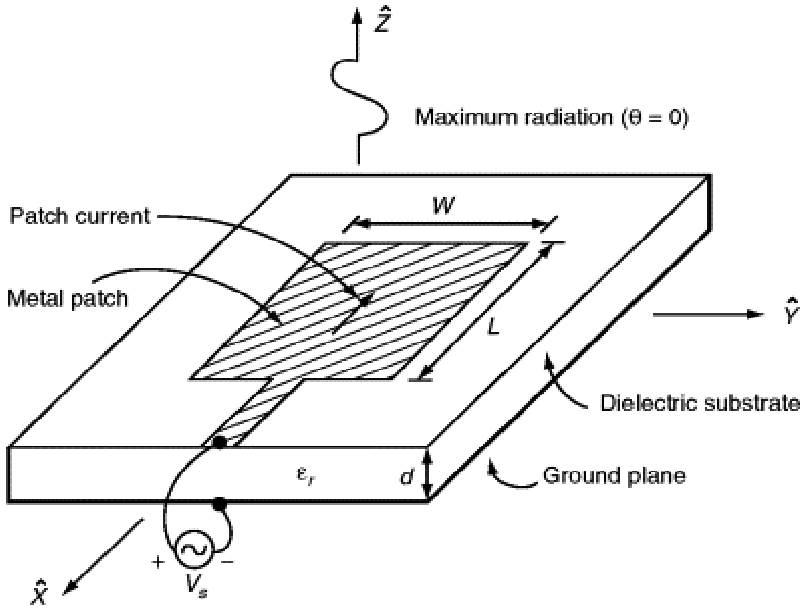


Fig1.4 Microstrip Antenna

1.4. WBAN

1.4.1. Introduction

Wearable Body Area Networks (WBANs) are wireless networks of wearable devices that are attached to or implanted in a person's body to monitor their health and physical activity. These devices are typically equipped with sensors to measure various physiological and environmental parameters, such as heart rate, body temperature, blood pressure, and oxygen saturation. WBANs are used in a variety of applications, including medical monitoring, sports and fitness tracking, and military and industrial settings. They can provide continuous and non-intrusive monitoring of a person's health and can be used to detect and diagnose diseases and medical conditions in real-time. The communication between the wearable devices in a WBAN is usually wireless, with the devices communicating through a wireless Personal Area Network (PAN) or through the Internet of Things (IoT) infrastructure. The use of wireless communication allows for seamless and continuous monitoring of the person's health without the need for wired connections. One of the key challenges in designing WBANs is ensuring that the devices are small, lightweight, and power-efficient, while still being able to communicate reliably with each other and with external devices. This requires the use of specialized antennas and communication protocols that are optimized for low power consumption and high reliability. Overall, WBANs have the potential to revolutionize the way we monitor and manage our health, enabling personalized and continuous monitoring of our physiological and environmental parameters.

1.4.2. Types of communication in body sensor networks

Body Sensor Networks (BSNs) are a type of wireless sensor network that comprises tiny wearable or implanted sensors that collect physiological data from the human body. There are several types of communication used in BSNs, including:

1.Wireless Body Area Networks (WBANs): WBAN is a type of wireless network that consists of a set of body-worn or implanted sensors that communicate with each other and with an external device, such as a smartphone or a central server, using wireless communication technologies, such as Bluetooth, ZigBee, or Wi-Fi. Body-Centric Wireless Communication: This type of communication involves using the human body as a communication medium. For example, the Galvanic Coupling (GC) technique can transmit signals through the body using electrodes placed on the skin.

2.Wireless Sensor Networks (WSNs): A WSN is a network of wireless sensors that can be deployed on or around the human body to monitor physiological data. The sensors communicate with each other and with a central device, such as a laptop or a smartphone, using wireless communication technologies.

3.Mobile Ad-Hoc Networks (MANETs): A MANET is a type of wireless network in which mobile devices communicate with each other without the need for a fixed infrastructure. MANETs can be used in BSNs to enable communication between wearable or implanted sensors and other devices. Overall, the type of communication used in a BSN depends on various factors, including the type of sensor, the data transmission rate, the range of communication, and the power consumption requirements.

1.4.2.1. In-body Communication

In-body communication In-body communication (IBC) is a type of communication technology that uses the human body as a transmission medium to transfer information between electronic devices implanted inside the body or worn on the skin. IBC has emerged as a promising alternative to traditional wireless communication technologies in various medical applications, such as implantable medical devices, telemedicine, and body area networks. There are two main types of IBC: galvanic coupling (GC) and capacitive coupling (CC).

1.Galvanic Coupling: In GC, the electronic devices communicate with each other by transmitting electrical signals through the tissue and fluids inside the body. This is achieved by placing electrodes on the skin or implanting them inside the body. The electrodes emit electrical signals that propagate through the body, and the receiving device picks up these signals.

2.Capacitive Coupling: In CC, the electronic devices communicate with each other by modulating the electrical field between two electrodes. This method does not require direct contact between the electrodes and the tissue, but rather uses the body's capacitance as a transmission medium. IBC has several advantages over traditional wireless communication technologies, including lower power consumption, higher data transfer rates, and improved security. However, it also has some limitations, such as the attenuation of signals due to the variability of the tissue and fluids inside the body, which can affect the transmission range and reliability.

1.4.2.2. On-body Communication

on-body communication On-body communication (OBC) is a type of communication technology that uses the human body as a transmission medium to transfer information between electronic devices worn on the skin or clothes. OBC can be used in various applications, including wearable technology, healthcare, and sports and fitness. There are different types of OBC, including:

1.Radio Frequency Identification (RFID): RFID is a wireless technology that uses radio waves to transmit data between a reader and a tag attached to an object or person. RFID tags can be attached to clothing or worn on the skin to enable OBC.

2.Near Field Communication (NFC): NFC is a wireless technology that enables short-range communication between electronic devices. NFC-enabled devices can communicate by placing them in close proximity to each other, such as holding a smartphone close to a wearable device.

3.Bluetooth: Bluetooth is a wireless technology that enables communication between electronic devices over short distances. Bluetooth-enabled wearable devices can communicate with smartphones, tablets, or other Bluetooth-enabled devices. ZigBee: ZigBee is a low-power wireless technology that enables communication between electronic devices over short distances. It is used in various applications, including home automation and healthcare.

OBC has several advantages over traditional wireless communication technologies, including low power consumption, high data transfer rates, and improved security. However, it also has some limitations, such as interference caused by clothing or other objects, which can affect the transmission range and reliability.

1.4.3. Main components of WBAN

Wireless Body Area Networks (WBANs) are a type of wireless network that comprises tiny sensors worn or implanted on the human body to monitor various physiological data. The main components of a WBAN include:

1.Wearable Sensors: These are small electronic devices that can be attached to the body or implanted under the skin to monitor various physiological data, such as heart rate, blood pressure, temperature, and oxygen saturation. These sensors can communicate with other devices in the WBAN using wireless communication technologies, such as Bluetooth or Zigbee.

2.Processing Unit: The processing unit is responsible for collecting, processing, and analyzing the data collected by the wearable sensors. This unit can be located on the wearable device or on a separate device, such as a smartphone or a laptop.

3.Communication Module: The communication module is responsible for transmitting the data collected by the wearable sensors to other devices in the WBAN or to a remote server. This module can use various wireless communication technologies, such as Bluetooth, Zigbee, or Wi-Fi, depending on the requirements of the application. Power Source: The power source is responsible for supplying power to the wearable sensors and the processing and communication units. Depending on the type of device and the application, the power source can be a battery, a solar cell, or a wireless charging system.

4.Sensor Nodes: Sensor nodes are the devices that are responsible for collecting physiological data from the human body. They are often worn or implanted on the body and are equipped with various types of sensors to monitor different physiological parameters. Sensor nodes are designed to be low-power devices and use wireless communication technologies to transmit data to the gateway node.

5.Gateway Nodes: Gateway nodes are the devices that receive the data transmitted by the sensor nodes and perform data processing, aggregation, and compression. They are responsible for managing the network and ensuring that the data is transmitted efficiently and reliably. Gateway nodes can also perform more advanced data processing tasks, such as signal processing, data fusion, and pattern recognition. They can also implement various security mechanisms to protect the data from unauthorized access or interception.

6.Wireless Communication Technologies: WBANs use various wireless communication technologies to transmit data between the sensor nodes and the gateway node. Some of the common wireless technologies used in WBANs include Bluetooth, Zigbee, and Wi-Fi. The choice of wireless technology depends on factors such as data rate, range, power consumption, and interference. Power Management: Since sensor nodes in WBANs operate in close proximity to the human body, they need to be designed to be low-power devices to minimize the energy consumed. Power management techniques, such as duty cycling, sleep modes, and energy harvesting, are used to conserve power and extend the battery life.

1.4.3.1 Sensor nodes

In Wireless Body Area Networks (WBANs), sensor nodes are small electronic devices that are worn or implanted on the human body to monitor various physiological data, such as heart rate, blood pressure, temperature, and oxygen saturation. The sensor nodes in a WBAN are similar to those used in wireless sensor networks (WSNs), but they are designed to be small, low-power, and capable of operating in close proximity to the human body. The main components of a sensor node in a WBAN include:

1.Sensor: The sensor is the primary component of the node that collects physiological data from the human body. The sensor can be attached to the skin or implanted under the skin to monitor various physiological parameters, such as heart rate, blood pressure, temperature, and oxygen saturation.

2.Microcontroller: The microcontroller is responsible for processing the data collected by the sensor and controlling the operation of the node. It is often a low-power microcontroller that is designed to minimize power consumption.

3.Communication Module: The communication module is responsible for transmitting the data collected by the sensor to other devices in the WBAN or to a remote server. It can use various wireless communication technologies, such as Bluetooth, Zigbee, or Wi-Fi, depending on the requirements of the application.

4.Power Source: The power source is responsible for supplying power to the sensor node. It can be a battery, a solar cell, or a wireless charging system, depending on the requirements of the application.

5.Types of Sensors: Sensor nodes in WBANs can be equipped with various types of sensors to monitor different physiological parameters. Some of the common sensors used in WBANs include electrocardiogram (ECG) sensors for monitoring heart rate and rhythm, electroencephalogram (EEG) sensors for monitoring brain activity, electromyography (EMG) sensors for monitoring muscle activity, and temperature sensors for monitoring body temperature.

6.Power Management: Sensor nodes in WBANs are designed to be low-power devices since they operate in close proximity to the human body and need to minimize the energy consumed. They often use power management techniques, such as duty cycling, sleep modes, and energy harvesting, to conserve power and extend the battery life. Placement and Design: The placement and design of sensor nodes in WBANs are critical factors that can affect the accuracy and reliability of the data collected. The sensor nodes need to be placed in a way that minimizes interference from other electronic devices and ensures accurate readings. The design of the sensor nodes also needs to be optimized for comfort, safety, and durability, since they are worn or implanted on the human body.

7.Data Transmission: Sensor nodes in WBANs transmit data wirelessly to the gateway node or other devices in the network. They can use various wireless communication technologies, such as Bluetooth, Zigbee, or Wi-Fi, depending on the requirements of the application. The data transmitted can be raw data or pre-processed data, depending on the processing capabilities of the sensor node.

8.Calibration and Maintenance: Sensor nodes in WBANs require periodic calibration and maintenance to ensure accurate readings and reliable operation. Calibration involves adjusting the sensors to correct for any drift or deviation from the expected values. Maintenance involves checking the battery life, updating the firmware, and replacing any worn-out or damaged components.

Overall, sensor nodes in a WBAN play a critical role in monitoring physiological data from the human body and enabling the operation of healthcare applications, such as remote patient monitoring, fall detection, and chronic disease management. They are designed to be small, low-power, and capable of operating in close proximity to the human body.

They can be equipped with various types of sensors, use power management techniques to conserve energy, need to be designed and placed optimally, transmit data wirelessly, and require calibration and maintenance to ensure accurate readings and reliable operation.

1.4.3.2 Gateway nodes

In Wireless Body Area Networks (WBANs), gateway nodes are devices that serve as a bridge between the sensor nodes worn or implanted on the human body and the outside world. The gateway node acts as a central hub that collects data from the sensor nodes and transmits it to other devices in the network or to a remote server. The main components of a gateway node in a WBAN include:

1.Communication Module: The communication module is responsible for receiving data from the sensor nodes and transmitting it to other devices in the network or to a remote server. It can use various wireless communication technologies, such as Bluetooth, Zigbee, or Wi-Fi, depending on the requirements of the application.

2.Microcontroller: The microcontroller is responsible for processing the data received from the sensor nodes and controlling the operation of the gateway node. It can perform tasks such as data aggregation, filtering, and compression to reduce the amount of data transmitted over the network.

3.Power Source: The power source is responsible for supplying power to the gateway node. It can be a battery or a wired power source, depending on the requirements of the application.

4.Storage: The gateway node may have built-in storage for temporarily storing data received from the sensor nodes before transmitting it to other devices in the network or to a remote server.

5.Data Processing: In addition to data aggregation, filtering, and compression, gateway nodes in WBANs can also perform more advanced data processing tasks, such as signal processing, data fusion, and pattern recognition. These tasks can enable the development of more sophisticated healthcare applications, such as fall detection, activity recognition, and emotion recognition.

6.Security: Gateway nodes in WBANs also play a critical role in ensuring the security and privacy of the data transmitted over the network. They can implement various security mechanisms, such as authentication, encryption, and access control, to protect the data from unauthorized access or interception. Network Management: Gateway nodes can also perform network management tasks, such as routing, topology management, and quality of service (QoS) management. These tasks can optimize the performance and reliability of the network and ensure that the data is transmitted efficiently and reliably.

7.Integration with Other Systems: Gateway nodes can also integrate with other systems, such as electronic health record (EHR) systems, mobile apps, and cloud platforms. This can enable the sharing of data between different healthcare providers, facilitate remote patient monitoring, and enable more advanced analytics and decision-making.

Overall, the gateway node plays a critical role in enabling communication between the sensor nodes worn or implanted on the human body and other devices in the network or to a remote server. It can perform data aggregation and filtering to reduce the amount of data transmitted over the network and can store data temporarily before transmitting it to other devices. The gateway node is an important component of a WBAN that enables the development of healthcare applications, such as remote patient monitoring and chronic disease management.

1.4.4. Standards

There are several standards that have been developed for Wireless Body Area Networks (WBANs) to ensure interoperability, compatibility, and reliability. Some of the important standards in WBANs include:

1.IEEE 802.15.6: This is a standard developed by the Institute of Electrical and Electronics Engineers (IEEE) for wireless body area networks. It specifies the physical layer and medium access control layer for WBANs and defines several modes of operation, including low-power, high-data rate, and ultra-wideband modes.

2.ISO/IEEE 11073: This is a family of standards developed jointly by the International Organization for Standardization (ISO) and the IEEE for medical device communication. It defines a standard communication protocol between medical devices, including those used in WBANs, to ensure interoperability and compatibility.

3.Continua Health Alliance: This is an industry alliance that develops interoperability standards for healthcare devices and systems. It has developed a set of guidelines and specifications for WBANs that ensure compatibility and interoperability between devices from different manufacturers.

4.Zigbee Health Care: This is a standard developed by the Zigbee Alliance for healthcare applications, including WBANs. It defines a set of profiles and interoperability standards that enable wireless communication between healthcare devices, including those used in WBANs.

5.Bluetooth Health Device Profile: This is a standard developed by the Bluetooth Special Interest Group (SIG) for healthcare applications, including WBANs. It defines a set of profiles and interoperability standards that enable wireless communication between healthcare devices using Bluetooth technology.

These standards ensure that devices and systems used in WBANs are interoperable, compatible, and reliable, which is critical for ensuring the safety and efficacy of healthcare applications. They also provide a common framework for manufacturers, healthcare providers, and regulators to develop and evaluate WBAN technologies.

6.IEEE 802.15.4: This is a standard developed by the IEEE for low-rate wireless personal area networks (LR-WPANs), including WBANs. It specifies the physical layer and media access control layer for LR-WPANs and defines several modes of operation, including low-power, low-latency, and high-reliability modes.

7.IEEE P928: This is a standard currently under development by the IEEE for a reference architecture for WBANs. It aims to provide a common framework for the design and implementation of WBANs and to facilitate interoperability and compatibility between different WBAN systems.

8.Wireless Medical Telemetry Service (WMTS): This is a service provided by the Federal Communications Commission (FCC) in the United States for the wireless transmission of medical data, including data from WBANs. It operates in the frequency range of 608-614 MHz, 1395-1400 MHz, and 1427-1432 MHz, which are reserved exclusively for medical telemetry applications.

9.European Commission (EC) initiatives: The EC has initiated several research and development projects related to WBANs, such as the European Research Area on Wireless Sensor Networks for Health (ERASME) and the Advancing Reliable Wireless Medical Devices (ARTEMIS) project. These initiatives aim to develop advanced technologies and systems for remote patient monitoring, medical diagnosis, and treatment.

10.International Telecommunication Union (ITU) initiatives: The ITU has developed several recommendations related to WBANs, such as the ITU-T Recommendation H.810, which provides guidelines for the design and implementation of WBAN systems. The ITU is also involved in the development of international standards and regulations for medical devices and wireless communication systems.

These standards and initiatives are critical for the development and adoption of WBAN technologies and systems. They provide a common framework for manufacturers, healthcare providers, and regulators to design, evaluate, and deploy WBAN systems that are interoperable, compatible, and safe. They also facilitate the integration of WBANs into existing healthcare systems and the development of new applications for remote patient monitoring, healthcare management, and medical research. Regenerate response

1.4.5. Applications

Wireless Body Area Networks (WBANs) have a wide range of applications in healthcare, sports, and other fields. Some of the common applications of WBANs include:

1.Remote patient monitoring: WBANs can be used to monitor the health status of patients remotely, without requiring them to visit a hospital or clinic. WBANs can monitor vital signs, such as heart rate, blood pressure, temperature, and respiratory rate, and transmit the data to healthcare providers for analysis and diagnosis. This can help to detect health problems early, prevent complications, and reduce healthcare costs.

2.Rehabilitation: WBANs can be used to monitor the movements and activities of patients during rehabilitation. This can help to track progress, detect deviations from the treatment plan, and provide feedback to patients and therapists. WBANs can also be used to deliver personalized exercise programs and monitor adherence to the programs.

3.Sports and fitness: WBANs can be used to monitor the performance and health of athletes and fitness enthusiasts. WBANs can monitor vital signs, such as heart rate, breathing rate, and blood oxygen levels, as well as movements and activities, such as steps taken, distance traveled, and calories burned. This can help to optimize training programs, prevent injuries, and improve overall performance.

4.Elderly care: WBANs can be used to monitor the health and well-being of elderly people who live alone or in care homes. WBANs can monitor vital signs, movements, and activities, as well as detect falls, wanderings, and other emergency situations. This can help to provide timely assistance, prevent accidents, and improve the quality of life for elderly people. 5.Military and emergency services: WBANs can be used to monitor the health and performance of soldiers, firefighters, and other emergency responders. WBANs can monitor vital signs, movements, and environmental conditions, such as temperature, humidity, and air quality. This can help to detect health problems early, prevent accidents, and provide timely assistance in emergency situations.

6.Chronic disease management: WBANs can be used to monitor patients with chronic diseases, such as diabetes, asthma, and heart disease. WBANs can monitor vital signs, such as blood glucose levels, lung function, and heart rate variability, and transmit the data to healthcare providers for analysis and diagnosis. This can help to improve disease management, prevent complications, and reduce healthcare costs.

7.Sleep monitoring: WBANs can be used to monitor the sleep patterns and quality of patients. WBANs can monitor vital signs, such as heart rate, breathing rate, and oxygen saturation, as well as movements and activities during sleep. This can help to diagnose sleep disorders, such as sleep apnea, and provide personalized treatment recommendations.

8.Drug delivery: WBANs can be used to deliver drugs and other therapies to patients. WBANs can include implantable sensors and drug delivery devices that can be controlled remotely. This can help to improve drug efficacy, reduce side effects, and enhance patient compliance.

9.Smart clothing: WBANs can be integrated into smart clothing, such as shirts, pants, and shoes. This can enable continuous monitoring of vital signs, movements, and environmental conditions, without requiring additional sensors or devices. Smart clothing can also be used to provide personalized feedback and coaching for sports and fitness activities.

10.Human-computer interaction: WBANs can be used to enable new forms of human-computer interaction, such as gesture recognition, brain-computer interfaces, and augmented reality. WBANs can provide real-time feedback and control signals based on the user's physiological and environmental state. This can enhance the user's experience and performance in various applications, such as gaming, virtual reality, and industrial control.

These are just some of the many applications of WBANs. As the technology continues to evolve and improve, new applications are likely to emerge in healthcare, sports, and other fields. As the technology continues to evolve and improve, new and innovative applications are likely to emerge in various fields.

CHAPTER 2

LITERATURE REVIEW

The suggested antenna is a polymer-based wide-band antenna array that is flexible, light, low profile, resilient, and utilised for changeable magnetic head imaging. consists of 4 x 4 radiating 10 - EBG unit cells surrounding the feeding network and 4 x 4 DNM unit cells that are positioned on the antenna's back side. It is embedded in a poly di-methyl siloxane [PDM] substrate. Following that, eight antenna arrays are evaluated using a 3D SAM head Phantom that mimics the typical characteristics of a real human head. Contucal imaging algorithm is the algorithm. [1]

A re-configurable multi-dipole and dinner with 0°, Plus +45°, 90°, and -45° polarisations for improving the wireless link quality of bwcs shows that it is effective to prevent polarisation mismatching, maintain the optimal transmission link, and predict the orientations of the implantable antenna inside the human body, but it also has appealing features like polarisation reconfigurability, White Band, and stable radiation pattern that lead to its use in bidirectional communications. [2]

The intraoral tongue drive system [itds] is a wireless assistive device that recognises voluntary tongue motions from users and converts them into user-defined instructions so they may control powered wheelchairs and access computers. Three bands—27, 433, and 915 MHz—were covered by the new antenna, which was modelled using a real human head in both open and closed mouth situations in hfss and xfd TD remcom. The matching algorithm for next generations detects interference and shifts to a new band in collaboration with the SDR receiver. It will be fully implemented on chips. [3]

The intraoral tongue drive system (ITDS) is a wireless technology that helps people with disabilities to control computers and powered wheelchairs by detecting their tongue movements and converting them into specific commands. The system operates on three different frequency bands (27 MHz, 433 MHz, and 915 MHz), and an antenna was simulated using HFSS and XFd TD Remcom with a realistic human head model in both open and closed mouth scenarios. The upcoming Generations matching algorithm will be integrated into a chip and will be able to detect any interference and automatically switch to a different frequency band in coordination with the SDR receiver. [4]

The wideband wearable button antenna was developed by analyzing the ground's characteristic modes and identifying the appropriate location for the button on the ground. This approach achieved a wide frequency band of around 2.4 GHz, making the antenna ideal for large-scale industrial production due to its simple topology and robust performance. The antenna design combines flexibility, reconfigurability, and variability, integrating two orthogonal polarization with a polarization-dependent artificial magnetic conductor (AMC) that has dual-band reflection phase. The proposed antenna was tested for both flat and curved configurations, and it was also measured on a human body. The results indicate that the specific absorption rate (SAR) level is reduced when using the AMC. [6]

A low profile, CPW fed slotted triangular monopole antenna was design for WBAN applications which resonates at 3.5 ghz, for wi Max wireless communication, and 5.8 ghz, of the ism band, at which good impedance matching was achieved. Using of 4 x 4 AMC array AMC array the game and reduced the SAR are which led to its recognition invariable medical applications for specifically remote monitoring the Healthcare of diabetic patients. [7]

The dual-band property of the novel structure is achieved by combining a patch antenna and a slot dipole. To effectively suppress back radiation and minimize electromagnetic coupling with the body, an artificial magnetic conductor (AMC) is utilized. The topology is simple, making the manual fabrication procedure straightforward. These features make it suitable for use in wireless body area network (WBAN) and wireless local area network (WLAN) applications. [8]

The integrated antenna has a wider bandwidth compared to an equivalent microstrip patch antenna. Specifically, it has a bandwidth of 4% at 2.45 GHz and 16% at 5.5 GHz, whereas the patch antenna has a bandwidth of 2.5% and 4.6%, respectively. The antenna design includes an electromagnetic band gap (EBG) structure, which effectively reduces back radiation and the specific absorption rate (SAR) values by up to a factor of 20. The antenna also exhibits higher gain performance. Results indicate that the antenna is capable of tolerating bending in either plane when shaped around polystyrene formers or human arms and legs. .[9]

A low-profile microstrip monopole antenna with an injected printed electromagnetic band gap (EBG) array and integrated artificial magnetic conductor (AMC) reflector has been developed. The antenna design has resulted in improved gain, which has been increased up to 8.44 dBi. The performance of the antenna has been evaluated on a phantom, and the results indicate that it is suitable for use in wearable electronics applications. [10]

The paper presented a flexible compact printed monopole antenna design integrated with a miniaturized slotted JC AMC ground plane for medicine applications. To eliminate the impedance mismatch and frequency shift caused by the human tissues proximity and to reduce electromagnetic radiation towards patience body, AMC ground plane is used. The bandwidth is 18% at 2.45 ghz, SAR reduction 64% of the same antenna without integration of amc, low susceptibility to Performance, degradation in terms of return loss and shift in the resonant frequency when confirmed on curved surface for the proposed antenna. [11]

The designed antenna is a compact and semi-flexible 2x1 EBG-backed planar monopole antenna that has excellent size and gain characteristics. It enhances radiation efficiency with a fractional bandwidth of 4.8% and a measured gain of 6.88 dBi in the ISM band, which is significantly greater than the gain of a conventional planar monopole antenna. The antenna design also reduces specific absorption rate (SAR) levels, making it suitable for use in various biosensors or medical monitoring applications. [12]

The article describes the design and analysis of a dual-band fractal antenna integrated with a square slotted electromagnetic band gap (EBG) for wearable applications. The use of the EBG has resulted in a considerable reduction in specific absorption rate (SAR) and back radiation in both the bands. The antenna is capable of covering the GSM 1800 and ISM 2.5 frequency bands. [13]

The research has focused on the examination of a textile variable metamaterial surface (MSA) for 5 GHz wireless body area network (WBAN) applications. The

MSA has a low profile of 4 mm (0.07 wavelength) and occupies a small area of 42 mm x 28 mm (0.77 wavelength x 0.51 wavelength). The results show a wider impedance bandwidth of 940 MHz and a higher measured gain of 6.7 dBi. The specific absorption rate (SAR) value indicates that the MSA is safe to use on different human tissues or under different bending conditions. [14]

The actual antenna has exhibited performance metrics that are closely aligned with the simulation predictions, achieving a 5.5% wideband impedance bandwidth, a gain of approximately 6.2 dBi, and a front-to-back ratio greater than 23 dB, which is superior to conventional patch antennas. Additional numerical simulations and experimental measurements have demonstrated that the antenna is durable against structural deformation and loading effects of human tissue, as well as possible impacts of environmental variations. [15]

This paper presents a multi-frequency and dual-mode microstrip antenna that utilizes a mushroom-structured ground plane, which has two patch-like modes (n=+/-1) and one monopolar mode (m=0) in between them. The antenna's working principle is analyzed using both CRLH theory and MTL theory. Despite the infinite wavelength mode obtained for the n=1 mode by the square radiating patch, the LP in the n=0 mode remains unchanged, demonstrating that the single-probe fed antenna possesses characteristics such as a low profile, radiation pattern, selectivity, and polarization diversity that are necessary in modern wireless communications. [16]

Band, low profile microstrip line slot fed mushroom antenna has been demonstrated with TM 10 and anti-fed TM20 mode that simultaneously excites well for broadband operation. Analysis of the field distribution and dispersion diagram of crlh mushroom and unit cell led to the deviation of empirical formulas to estimate the resonant frequencies of the two operating modes and made High dielectric constant substrate applicable to design Broadband patch antenna with thickness of 0.60 lambda, bandwidth of 25% with an average gain of 9.9 DBI, efficiency about 76% and good cross polarizations below minus 20 DB. [17]

The paper introduces a compact and high-performance array design for 5G sub 6 GHz and Wi-Fi systems using a HMS-based low-profile wideband antenna. The cross polarization levels and gain have been improved by using CMS antenna with the HMS antenna. The integration of shorting pins helps in suppressing surface waves. The 2x2 array design achieves an impressive bandwidth of 28%, an average gain of 10.9 dbi, radiation efficiency of around 68%, and a low cross-polarization level below -30 dB. [18]

The initial two LP antenna designs achieve improvement in gain and bandwidth by incorporating a microstrip (MS) with single and double loaded ICs, respectively. Furthermore, a compact CP antenna was developed by integrating a MS with a triangular IC loading pattern and diagonal slots below a LP monopole feed antenna. This was achieved by analyzing the electromagnetic response of the ICMS unit cell to the incident wave, leading to the realization of the ICMS's ability to support LP to CP conversion. [19]

The in-phase reflection characteristic of the AMC structure significantly enhance the radiation characteristics of the antenna in terms of antenna gain and front to back ratios which reduce the undesired electromagnetic radiation towards the human body. Are value is low and flexibility test in terms of antenna performance under crumpling conditions were carried out to see the effect of Shifting the zero in phase point from that of the flat AMC reflector. [20]

A conventional planner Yagi antenna was combined with s - AMC and D - AMC surfaces to change the direction of radiation from bidirectional endfire to near-endFire, off-axis, beam-tilt radiation. Material property characterization, such as permittivity and loss tangent, was performed for the flexible latex substrate. On Noble this depicts that the DMC improves the front to back ratio call Mom frequency D tuning radiation efficiency, and pick SAR level compared with a yagi antenna backed by S-AMC and without AMC. This is a novel technique. [21]

This paper proposes a low-profile metasurface antenna with quad-polarization reconfiguration capability. To achieve this, the design includes four switchable feeding probes connected by two specially designed spdt switches, which allow switching between two orthogonal LP modes and two orthogonal CP modes. As a result, the antenna has a wide operating bandwidth and high gain. [22]

To enhance gain and widen bandwidth, are low - profile suspended meta surface based antenna with small propagation constant of a TM surface wave in the operating frequency band that contributes to wireless applications has been introduced. [23]

This study examined three sub-wavelength antennas that use optimized composite double-layer arrays with a dual-resonant feeding mechanism to achieve a wide bandwidth. The design was based on a combination of Ray Optics analysis and periodic full-wave simulations. The resulting antennas achieved a gain of 16.3 DBI and a 3dB bandwidth of 10.9% with an S11 below -10 DB. [24]

Dispersion relation and radiation mechanism with full space beam - scanning performance is confirmed by simulation and measurement which led to the effect of the ground for h w s i w leaky - wave antenna. In Short this paper investigated that family of crlhsiw and hmciw leaky - wave antennas. [25]

The paper presents a multi-layered LWA based on CRLH-SIW for achieving consistent gain while scanning from backward to forward beams. The measured results showed consistent scanning gain with less than 3 dB variation across a frequency range from 8.25 to 12.8 GHz. The maximum gain of 12.8 was measured at 9.5 GHz, which improves the boresight radiation of the antenna. [26]

The study examines miniaturized CRLH-SIW transverse slot antennas in both open-ended and short-ended cases with one or two stages. Various order resonances, including negative, zeroth, and positive order modes, have been investigated, and the findings indicate that the proposed antennas exhibit relatively high radiation efficiency, increased directivity, and high gain. [27]

The IBSN represents a significant advancement from the widely-used body area sensor network. It offers a new technological platform for monitoring vital physiology, treating illnesses, and facilitating rehabilitation therapy. This system integrates a commercially available MICS transceiver, an SoC sensor node, and a wireless transcutaneous power charging system. It not only meets the ultra-low power requirements but also complies with the patient safety guidelines set by ICNIRP. [28]

The electromagnetic interaction between an antenna and the human head has been analyzed in the presence of materials and metamaterials. The study revealed that using materials can lead to a specific absorption rate (SAR) value of about 0.676 for a SAR 10 GM value, while using foot metamaterials can result in a SAR value of about 0.737 for a SAR 10 GM value. The 3D finite-difference time-domain (FDTD) method with a lossy-Debye model was utilized to show that placing materials and metamaterials between the antenna and the human head can reduce the peak SAR 10 GM value. [29]

The application of reflector patch elements for reducing the rear directed radiated field from a coplanar waveguide (CPW) fed asymmetric coplanar patch (ACP) antenna has been investigated. It has been demonstrated that the total power radiated in the rear hemisphere is decreased when a reflector patch is added to the device. [30]

A novel half-diamond shaped hybrid-wireless structure (HWSIW) topology was used to develop a dual-band wearable antenna, which was fabricated using textile materials and brass eyelets. The antenna design combines a ground plane and HWSIW technology to create a half-open cavity, which exhibits robust behavior when worn by a person. The device covers both the 2.4 and 5.8 GHz ISM bands, with a measured bandwidth of 4.9% and 5.1%, maximum measured gains of 4.1 and 5.8 DBI, and measured efficiency of 72.8% and 85.6% respectively. The impedance matching remained stable even when bent around a cylinder with a small radius of 40 mm. [31]

A miniaturized omnidirectional antenna can support both of mic and ISM band which are usuallyused in BIO Telemetry applications that presents an appropriate gain with a monopol like pattern in very compact size. [32]

A new monopole antenna has been developed using noble nanotechnology-enabled inkjet printing and an electromagnetic bandgap (EBG) structure. This design helps to reduce the on-body effects on variable wireless sensors. Compared to conventional surface-mounted chip antennas, this new design has demonstrated an improvement in on-body communication range by a factor of approximately 4. [33]

It has been shown that increasing the bandwidth of the artificial magnetic conductor (AMC) backing can significantly enhance the gain of inkjet-printed antennas on highly lossy substrates. By doing so, the device can achieve resonances with a 20% smaller electrical size, resulting in a 5-dB gain increase. [34]

A windmill-shaped crossed-dipole antenna has been designed to be flexible and avoid visual pollution. The device uses a square-shaped artificial magnetic conductor (AMC) plane instead of a perfect electric conductor (PEC) ground to enable off-body communications. The safety of electromagnetic radiation is demonstrated through analysis of specific absorption rate (SAR) and temperature performance. The device has been shown to enable wireless communication within a large scope in indoor line of sight (LOS) environments, as demonstrated by analysis of the link budget. This device is suitable for use in wireless body area network (WBAN) systems. [35]

A new compact planner and dinner have been developed to support operating mobile services, ISM applications, and wireless communication. This planner and dinner includes an EBG structure which helps to reduce the size of the device, eliminate interference between frequency bands, and lower the specific absorption rate (SAR) values. The device was simulated using the CST simulator and created using the photo-lithographic technique. [36]

CHAPTER 3

METAMATERIALS AND METASURFACES

3.1. METAMATERIALS

3.1.1. Introduction

Metamaterials are a class of artificial materials that are engineered to have properties not found in naturally occurring materials. They are typically composed of subwavelength-sized structures arranged in a periodic pattern, which gives them their unique properties. These structures can be designed to manipulate electromagnetic waves, sound waves, or other types of waves in ways that are not possible with conventional materials. The concept of metamaterials was first introduced in the late 1990s, and since then, they have attracted a great deal of attention from researchers in a wide range of fields, including physics, engineering, and materials science. One of the key properties of metamaterials is their ability to exhibit negative refractive index, which means that they can refract light in a direction opposite to that of conventional materials. This property has led to a wide range of potential applications, including lenses, cloaking devices, and superlenses capable of resolving features smaller than the wavelength of light. Metamaterials can also be engineered to have unusual mechanical properties, such as negative Poisson's ratio or high stiffness-to-weight ratio, which makes them attractive for applications in aerospace and other industries. Additionally, metamaterials can be designed to exhibit specific frequency response, gain, efficiency, and other properties that are important for various applications. The production of metamaterials typically involves nanofabrication techniques, such as electron beam lithography or 3D printing, which can be expensive and time-consuming. However, advances in manufacturing techniques and materials science are making it possible to produce metamaterials more efficiently and cost-effectively, which is expected to drive the development of new applications in the coming years.

3.1.2.Properties of metamaterials

Metamaterials have the potential to revolutionize many areas of science and technology. Here are some more examples of their potential applications:

1.Antennas: Metamaterials can be used to create antennas with high gain, low profile, and wide bandwidth. These antennas can be used in a variety of applications, such as wireless communication and radar systems.

2.Cloaking devices: Metamaterials can be engineered to bend light around an object, making it invisible to the observer. This property has the potential to be used in military applications, as well as in more mundane applications like hiding unsightly objects. Solar cells: Metamaterials can be used to improve the efficiency of solar cells by capturing a wider range of the solar spectrum and increasing the amount of light absorbed by the cell.

3.Sensors: Metamaterials can be used to create highly sensitive sensors for detecting a range of substances, from chemicals to biological molecules. These sensors can be used in a variety of applications, including medical diagnostics and environmental monitoring.

4.Terahertz imaging: Metamaterials can be used to create lenses and other components for terahertz imaging, which can be used to detect hidden weapons and other objects.
5.Soundproofing: Metamaterials can be used to create materials with negative acoustic properties, which can be used to block sound and reduce noise pollution.

6.Negative refractive index: Metamaterials can be designed to have a negative refractive index, meaning that they can refract light in a direction opposite to that of natural materials. This property allows metamaterials to be used in applications like lenses and cloaking devices.

7.Electromagnetic properties: Metamaterials can be engineered to have specific electromagnetic properties, such as high or low permittivity, permeability, or conductivity. This makes them useful for applications like antennas, sensors, and electromagnetic shielding.

8.Acoustic properties: Metamaterials can be designed to have specific acoustic properties, such as negative acoustic impedance, which makes them useful for applications like soundproofing and noise reduction.

9.Mechanical properties: Metamaterials can be engineered to have unusual mechanical properties, such as negative Poisson's ratio, high stiffness-to-weight ratio, or tunable elasticity. This makes them useful for applications in aerospace, robotics, and other industries.

10.Frequency response: Metamaterials can be designed to have specific frequency response, such as resonant or non-resonant behavior, which makes them useful for applications like filters and sensors.

11.Thermal properties: Metamaterials can be engineered to have specific thermal properties, such as high or low thermal conductivity, which makes them useful for applications like thermoelectric devices and thermal management.

Overall, the properties of metamaterials can be tailored to meet specific application requirements, which makes them attractive for a wide range of applications in fields like optics, acoustics, electromagnetics, and mechanics. However, the production of metamaterials can be challenging, and many of the applications of metamaterials are still in the research and development stage.

3.2. Metasurfaces

3.2.1. Introduction

Metasurfaces are two-dimensional metamaterials that can manipulate electromagnetic waves with unprecedented precision and control. They are thin and planar structures, typically consisting of an array of subwavelength-sized scatterers arranged in a specific pattern. The unique design of these surfaces enables them to modify the amplitude, phase, and polarization of the incoming electromagnetic waves. Metasurfaces can be used to manipulate light in various ways, such as focusing, shaping, and steering the waves. They are particularly useful in the design of optical components, such as lenses, beam splitters, and polarizers. By manipulating the phase of the incoming light with high precision, metasurfaces can achieve the same effect as traditional bulky optical components but with a much thinner and more compact design. One of the most exciting applications of metasurfaces is in the field of holography, where they can be used to create high-resolution 3D images. By manipulating the phase of the incoming light with metasurfaces, it is possible to create a 3D image that appears to be floating in space. This technique has potential applications in fields like medical imaging, entertainment, and virtual reality. Metasurfaces are also being used in the development of new types of sensors and detectors. By modifying the properties of the incoming electromagnetic waves, metasurfaces can enhance the sensitivity and resolution of sensors, enabling them to detect very small changes in the environment. Overall, metasurfaces represent an exciting new area of research in the field of metamaterials, with potential applications in a wide range of fields, from optics and sensing to telecommunications and information technology.

3.2.1.Properties of metasurfaces

Metasurfaces have several unique properties that make them attractive for various applications. Some of these properties include: High precision control of electromagnetic waves: Metasurfaces can control the amplitude, phase, and polarization of electromagnetic waves with high precision, enabling them to manipulate light in unprecedented ways. Thin and lightweight design: Metasurfaces are typically thin and lightweight, making them easy to integrate into existing devices and systems. They are also more compact than traditional optical components, making them ideal for use in miniaturized devices. High efficiency: Metasurfaces can achieve high efficiency in manipulating electromagnetic waves, enabling them to perform complex tasks with minimal energy loss. Broadband operation: Some metasurfaces can operate over a broad range of frequencies, enabling them to manipulate light from different sources and at different wavelengths. Versatility: Metasurfaces can be designed to perform a wide range of functions, from focusing and steering light to polarizing and filtering it. Compatibility with existing fabrication techniques: Many metasurfaces can be fabricated using existing techniques, such as electron-beam lithography or laser patterning, making them easy to manufacture at scale. Overall, the unique properties of metasurfaces make them attractive for a wide range of applications, from optical components and holography to sensing and information technology.

3.3. CRLH-TL

3.3.1. Introduction

A CRLH transmission line (CRLH-TL) is a type of transmission line that exhibits both left-handed (LH) and right-handed (RH) characteristics. This means that it can support both forward and backward electromagnetic waves, unlike traditional transmission lines that only support forward waves. The term CRLH stands for composite right/left-handed, referring to the fact that the transmission line is made up of a composite structure of both LH and RH elements. Specifically, the line consists of an alternating series of inductive and capacitive elements that are arranged in a specific pattern to create the CRLH effect. CRLH-TLs have some unique properties that make them attractive for various applications, such as: Negative phase velocity: CRLH-TLs can exhibit a negative phase velocity, which means that the phase of the wave travels in the opposite direction to the wave itself. This property can be used to create novel devices, such as negative-refractive-index lenses and cloaking devices. Wideband operation: CRLH-TLs can operate over a wide range of frequencies, making them suitable for applications in telecommunications and radar systems. Compact size: CRLH-TLs are typically much smaller than traditional transmission lines, making them ideal for use in miniaturized devices and systems. Low dispersion: CRLH-TLs can exhibit low dispersion, meaning that the phase velocity does not vary significantly with frequency. This property is useful for applications that require precise control over the phase of the wave, such as in phased array antennas. Overall, CRLH-TLs represent an exciting area of research in the field of metamaterials, with potential applications in various fields, including telecommunications, radar systems, and antenna design.

CRLH-TLs have some additional interesting properties and applications:

1.Non-reciprocal operation: By introducing magnetic biasing or non-linear elements into the CRLH-TL structure, it is possible to create a non-reciprocal device, which means that the transmission properties of the line depend on the direction of propagation. This property is useful for creating isolators and circulators, which are essential components in many RF and microwave systems.

2.Metamaterial-inspired devices: CRLH-TLs are a type of metamaterial, which means that they can exhibit properties not found in natural materials. By combining CRLH-TLs with other metamaterial structures, it is possible to create novel devices, such as perfect lenses, superlenses, and electromagnetic bandgap structures. Applications in wireless power transfer: CRLH-TLs have been investigated for use in wireless power transfer systems, where they can be used to create highly efficient resonant circuits that can transfer power wirelessly over short distances.

3.Antenna design: CRLH-TLs can be used to design new types of antennas with improved performance. For example, by embedding CRLH-TLs in the antenna structure, it is possible to create antennas with increased bandwidth, gain, and directivity.

4.Sensing applications: CRLH-TLs have been investigated for use in sensing applications, such as in the detection of biological and chemical agents. By coating the CRLH-TL with a sensing material, changes in the transmission properties of the line can be used to detect the presence of the target substance.

Overall, CRLH-TLs represent an exciting area of research in the field of metamaterials, with potential applications in a wide range of fields, from wireless power transfer and antenna design to sensing and communications.

3.3.2. Applications of CRLH-TL

CRLH-TLs have several applications in various fields, some of which are listed below: Microwave and millimeter-wave engineering: CRLH-TLs are widely used in microwave and millimeter-wave engineering for the design of compact, high-performance filters, antennas, and amplifiers. They offer several advantages over conventional transmission lines, including increased bandwidth, improved power handling capacity, and reduced size and weight.

1.Metamaterial-based devices: CRLH-TLs are a type of metamaterial, which means they can be used to create devices that exhibit unique properties not found in natural materials. By combining CRLH-TLs with other metamaterial structures, it is possible to create novel devices such as perfect lenses, superlenses, and electromagnetic bandgap structures.

2.Wireless power transfer: CRLH-TLs have been investigated for use in wireless power transfer systems, where they can be used to create highly efficient resonant circuits that can transfer power wirelessly over short distances.

3.Sensing and detection: CRLH-TLs have been investigated for use in sensing applications, such as in the detection of biological and chemical agents. By coating the CRLH-TL with a sensing material, changes in the transmission properties of the line can be used to detect the presence of the target substance.

4.Medical applications: CRLH-TLs have potential applications in medical imaging and diagnostics, such as in the development of novel microwave imaging systems for breast cancer detection.

Overall, CRLH-TLs represent an exciting area of research with potential applications in a wide range of fields, from wireless power transfer and antenna design to sensing and communications.

Table 3.1: Difference table between metamaterials and other materials

Property	**Metamaterials**	**Other Materials**
Structure	Artificially designed with subwavelength periodicity	Naturally occurring or conventionally engineered
Electromagnetic properties	Can exhibit negative refractive index, negative permeability, and negative permittivity, leading to unique electromagnetic properties	Do not exhibit negative refractive index or other unique electromagnetic properties
Mechanical properties	Can be engineered to exhibit unusual mechanical properties, such as negative Poisson's ratio or high stiffness-to-weight ratio	Mechanical properties are typically determined by the composition and structure of the material
Frequency response	Can be designed to operate at specific frequencies, including microwave and terahertz frequencies	Frequency response varies depending on the material and application, and may be limited by the material properties
Gain	Can exhibit high gain in certain applications, such as antennas	Gain varies depending on the material and application, and may be limited by the material properties
Efficiency	Can exhibit high efficiency in certain applications, such as solar cells and sensors	Efficiency varies depending on the material and application, and may be limited by the material properties

Property	**Metamaterials**	**Other Materials**
Specific Absorption Rate (SAR)	Can be designed to exhibit low SAR in certain applications, such as biomedical devices	SAR varies depending on the material and application, and may be limited by regulatory limits and safety considerations
Applications	Used in antennas, cloaking devices, sensors, biomedical devices, and other electromagnetic applications	Used in a wide range of applications, such as building materials, electronics, and medical implants
Production	Produced using nanofabrication techniques, such as electron beam lithography or 3D printing	Produced using conventional manufacturing processes, such as casting or machining
Cost	Can be expensive to produce due to the specialized fabrication techniques required	Cost depends on the material and the production method, but is generally lower than for metamaterials

CHAPTER 4

CST AND ANTENNA DESIGN

4.1. CST Studio Suite

4.1.1. Introduction

CST Studio Suite is a collection of electromagnetic simulation software tools developed by Computer Simulation Technology (CST). The suite includes several tools for simulating electromagnetic phenomena in a wide range of applications, such as antenna design, microwave circuit analysis, electromagnetic compatibility (EMC), and electromagnetic interference (EMI). The purpose of this project is to provide an overview of the CST Studio Suite software and its applications in the field of electromagnetic simulation.

CST Studio Suite is designed to be user-friendly, with a graphical user interface (GUI) that allows users to easily create and modify their designs, define simulation settings, and analyze simulation results. It also supports a wide range of import and export file formats, allowing users to easily exchange data with other software packages.

In addition, CST Studio Suite provides advanced post-processing and visualization tools that allow users to analyze simulation results in detail. For example, users can visualize electromagnetic fields in 3D, plot S-parameters and radiation patterns, and perform parameter sweeps and optimization studies.

4.1.2. Software Overview

CST Studio Suite consists of several modules that allow users to simulate and analyze electromagnetic fields in different types of structures. The modules include:

1.CST Microwave Studio (CST MWS): This module is used for simulating high-frequency electromagnetic fields in microwave and RF devices. It includes a variety of solvers for simulating different types of structures, such as waveguides, antennas, filters, and amplifiers.

2.CST PCB Studio (CST PCBS): This module is used for simulating electromagnetic fields in printed circuit boards (PCBs). It includes features for modeling signal integrity, power integrity, and electromagnetic interference (EMI) in PCBs.

3.CST Cable Studio (CST CS): This module is used for simulating electromagnetic fields in cables and cable harnesses. It includes features for modeling signal integrity, crosstalk, and radiation effects in cables.

4.CST EM Studio (CST EMS): This module is used for simulating electromagnetic fields in complex 3D structures, such as automotive and aerospace components, medical devices, and industrial equipment.

4.1.3. Features

CST Studio Suite provides a range of simulation tools for electromagnetic analysis, including 3D electromagnetic field solvers, frequency and time domain analysis, circuit simulation, and thermal and mechanical analysis. Some of the key features of CST Studio Suite include:

1.3D Electromagnetic Field Solvers: CST Studio Suite includes a range of 3D electromagnetic field solvers, such as the Finite Integration Technique (FIT) and the Time Domain Integral Equation (TDIE) solver, which can simulate complex electromagnetic phenomena accurately and efficiently.

2.Frequency and Time Domain Analysis: CST Studio Suite can perform frequency domain analysis, such as S-parameter and scattering parameter (S-matrix) analysis, as well as time domain analysis, such as transient and pulse analysis.

3.Circuit Simulation: CST Studio Suite includes a circuit simulation tool that can simulate passive and active circuits, such as filters, amplifiers, and mixers.

4.Thermal and Mechanical Analysis: CST Studio Suite can also perform thermal and mechanical analysis of electromagnetic devices and systems, such as thermal management of electronic components and structural analysis of antennas.

5.Optimization: CST Studio Suite includes optimization tools that can be used to optimize the design of electromagnetic devices and systems based on predefined design goals and constraints.

4.1.4. Applications

CST Studio Suite is widely used in the field of electromagnetic simulation for a variety of applications, including:

1.Antenna design: CST MWS is used for designing and optimizing antennas for wireless communication systems, radar systems, and satellite systems.

2.Microwave circuit analysis: CST MWS is used for simulating and analyzing microwave circuits, such as filters, amplifiers, and oscillators.

3.EMC/EMI analysis: CST PCBS is used for simulating electromagnetic compatibility (EMC) and electromagnetic interference (EMI) in printed circuit boards (PCBs), electronic systems, and automotive components.

4.Automotive and aerospace design: CST EMS is used for simulating electromagnetic fields in complex 3D structures, such as automotive and aerospace components, to ensure electromagnetic compatibility and compliance with EMC standards.

5.Medical Imaging: CST Studio Suite can be used to simulate and optimize medical imaging devices, such as magnetic resonance imaging (MRI) and computed tomography (CT) scanners.

4.1.5. Conclusion

In conclusion, CST Studio Suite is a powerful set of electromagnetic simulation tools that is widely used in the field of electromagnetic simulation for a variety of applications. The software includes several modules that allow users to simulate and analyze electromagnetic fields in different types of structures, such as microwave devices, PCBs, cables, and complex 3D structures. CST Studio Suite has become an essential tool for engineers and researchers working in the fields of antenna design, microwave circuit analysis, EMC/EMI analysis, and automotive and aerospace design.

4.2. Antenna Design

4.2.1.Introduction

Microstrip patch antennas have become increasingly popular over the years, mainly due to their various advantages over conventional antennas. They are widely used in modern communication systems because of their low profile, lightweight, and low cost, making them ideal for applications where space is limited. Microstrip patch antennas are also easy to integrate with printed circuit boards, making them a popular choice among designers and engineers. One of the most common microstrip antennas is the rectangular patch antenna, which has a simple design and can operate at various frequencies. It consists of a thin, flat rectangular patch of conducting material, such as copper, on a dielectric substrate. The ground plane is placed on the opposite side of the substrate, separated by a thin layer of dielectric material. The feed mechanism, typically a coaxial probe, is connected to the patch through a small aperture in the ground plane. When excited with a signal, the patch radiates electromagnetic waves into free space. One of the main advantages of microstrip patch antennas is their compact size and low profile. This makes them ideal for applications where space is limited, such as in mobile devices like smartphones and tablets. The low profile design also means that they can be easily integrated with printed circuit boards, allowing for a simplified manufacturing process. In addition, they can be designed to operate at various frequencies, making them suitable for use in a wide range of communication systems. Another advantage of microstrip patch antennas is their low cost. They can be manufactured using standard printed circuit board techniques, which makes them an attractive option for mass production. The manufacturing process is also simpler compared to other antenna types, which further reduces the cost. So, microstrip patch antennas, and specifically the rectangular patch antenna, are widely used in modern communication systems due to their various advantages. Their compact size, low profile, ease of integration with printed circuit boards, and ability to operate at various frequencies make them ideal for a wide range of applications. Additionally, their low cost and simple manufacturing process make them an attractive option for mass production.

4.2.2.Construction Of Antenna Using CST

The design and construction of a microstrip rectangular patch antenna can be done using electromagnetic simulation software, such as CST Microwave Studio. The software allows for the optimization of the antenna's parameters, such as the dimensions of the patch and substrate, feed position, and ground plane dimensions. The design process typically involves starting with a rough estimate of the antenna's dimensions and then using simulation software to optimize its performance. Once the design is finalized, the construction of the antenna can be done using standard printed circuit board techniques. After the antenna is constructed, it can be analyzed using the simulation software to verify its performance. The software can provide information about the antenna's radiation pattern, gain, bandwidth, and impedance matching, among other parameters. The results of the analysis can then be compared to the design specifications to determine whether the antenna meets the requirements. If the performance is not satisfactory, the design can be further optimized and the process repeated until the desired performance is achieved. In this section, we will provide an overview of the design process using CST Microwave Studio for a microstrip rectangular patch antenna, unit cell and proposed antenna. To construct a microstrip rectangular patch antenna, follow the below steps:

1.Prepare the Ground Plane: The first step is to prepare the ground plane, which is a conductive sheet that acts as a reflector for the antenna. The ground plane is usually made of copper and can be cut into a square or rectangular shape, depending on the desired antenna dimensions. As shown in Fig.4.1, the ground plane is placed at the bottom.

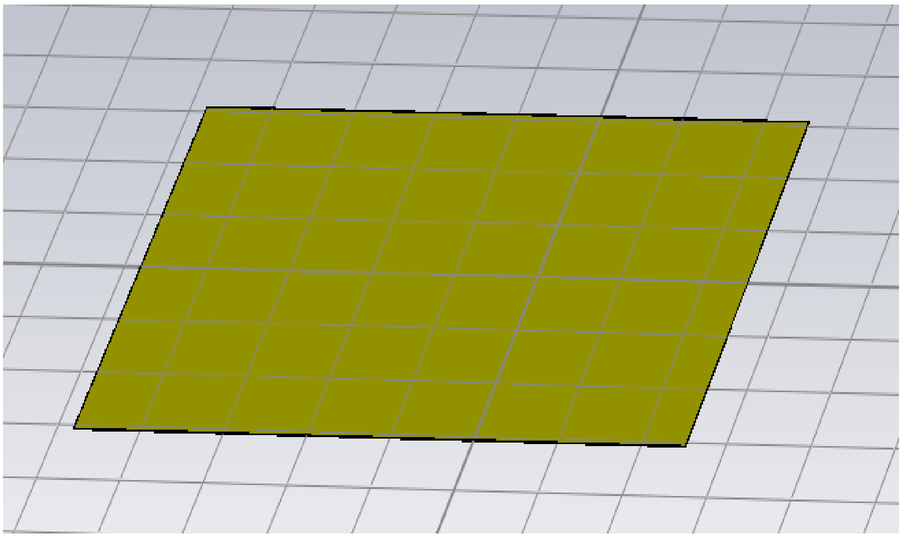


Fig.4.1 Ground Plane

2.Cut the Substrate: The next step is to cut the dielectric substrate, which is a non-conductive material that separates the ground plane from the patch. The substrate is usually made of materials such as FR-4, Rogers, or Teflon. The substrate is cut into the desired shape and size, which is usually slightly larger than the ground plane. The substrate is then placed on top of the ground plane, as shown in Fig.4.2.

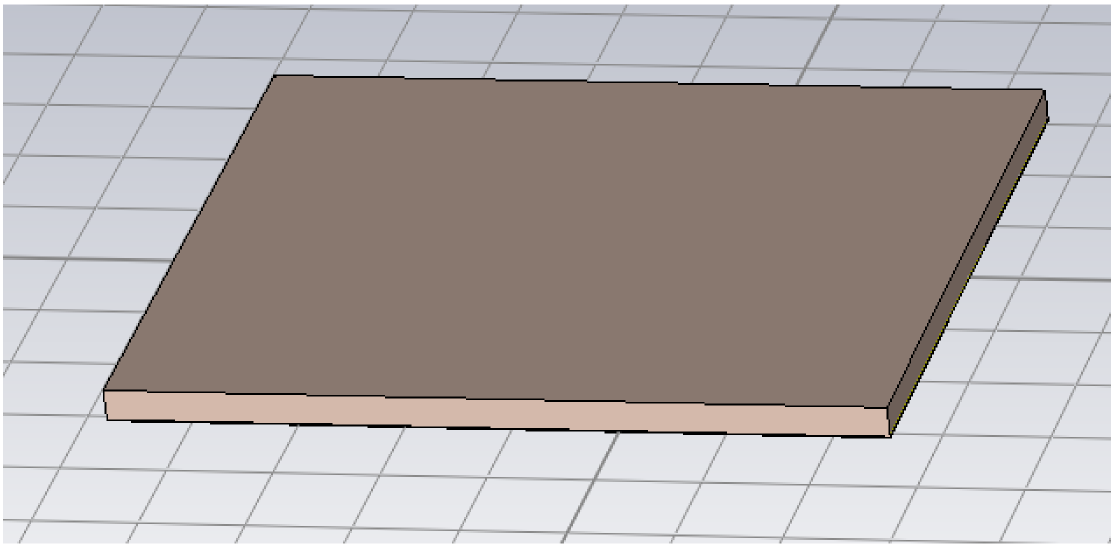


Fig.4.2 Substrate On Ground Plane

3.Attach the Patch: The patch is made of a conductive material such as copper and is cut into the desired shape and size. The most common shape is rectangular, but patches can also be circular, triangular, or other shapes. The patch is then placed on top of the substrate, in the center, as shown in Fig.4.3. The patch can be attached to the substrate using adhesive or other methods.

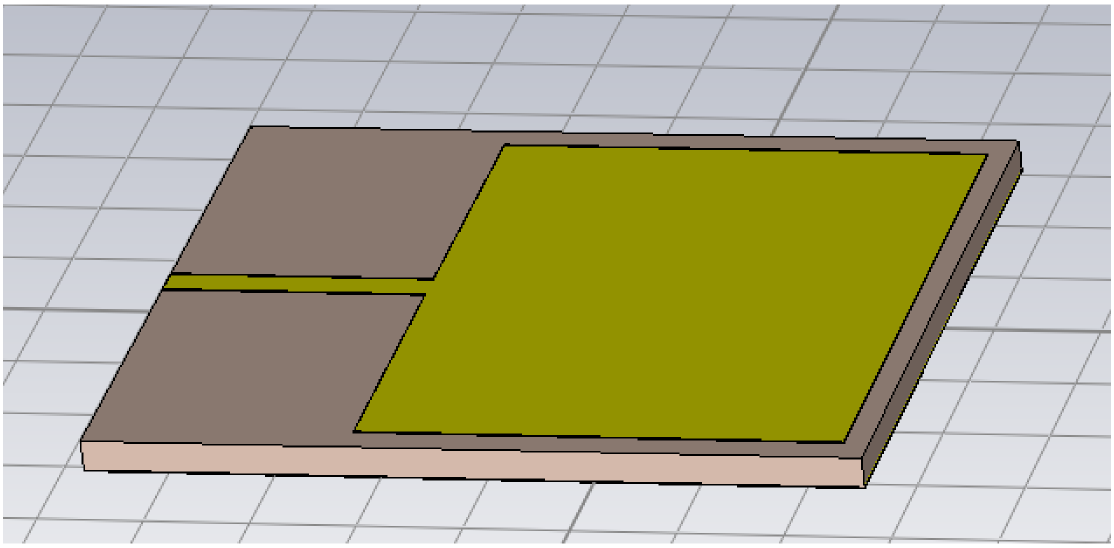


Fig.4.3.Rectangular Patch on Substrate

To construct the unit cell, follow the below steps:

1.Prepare the Ground Plane: The first step is to prepare the ground plane for the unit cell, which is a conductive sheet that acts as a reflector for the antenna.

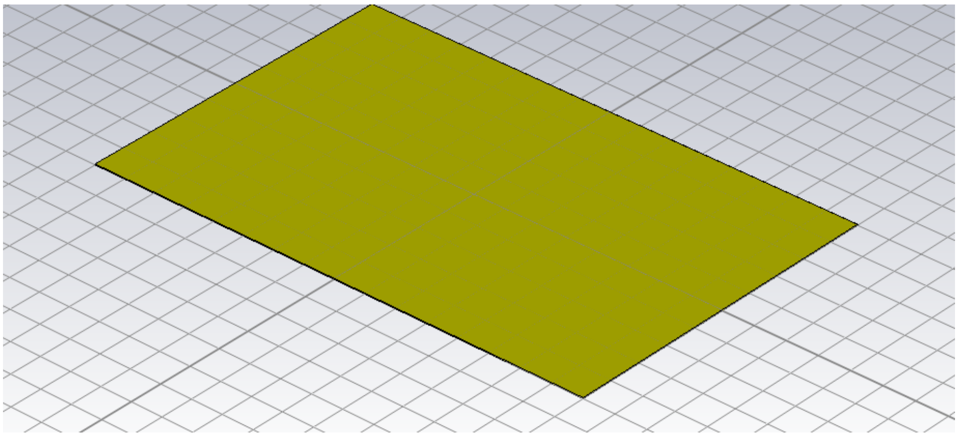


Fig.4.4.Ground Plane Of The Unit Cell

2.Cut the Substrate: The next step is to cut the dielectric substrate, which is a non-conductive material that separates the ground plane from the patch. The substrate is usually made of materials such as FR-4, Rogers, or Teflon.

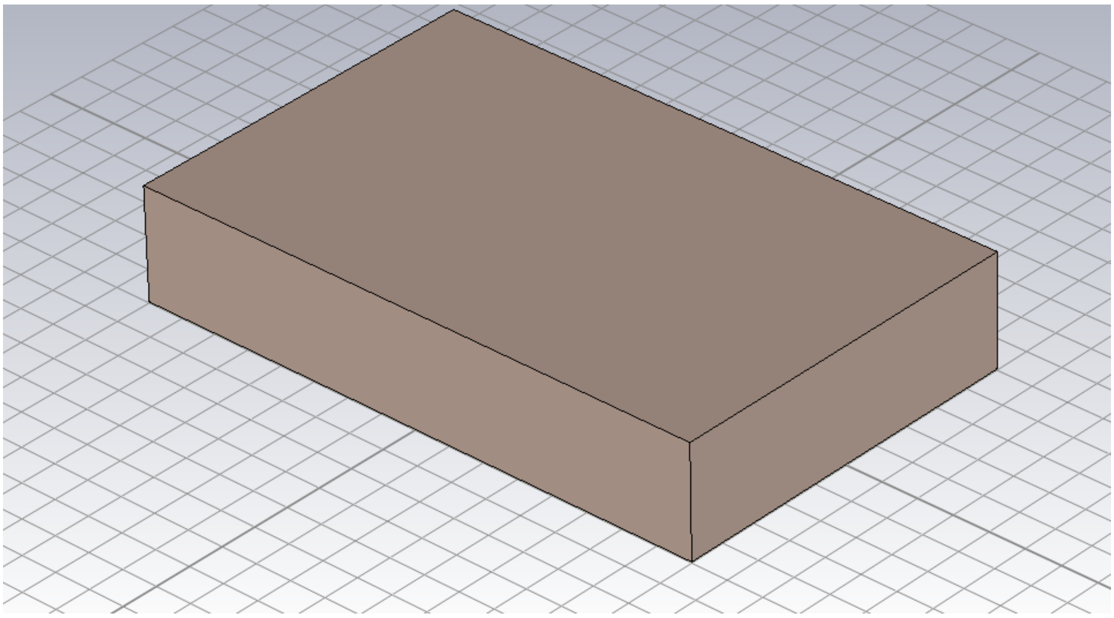


Fig.4.5.Substrate Of The Unit Cell

3.Attach the Patch: The patch is made of a conductive material such as copper and is cut into the desired shape and size.To enhance the performance of the rectangular patch antenna, it is possible to modify the shape of the patch and add a complementary split ring resonator (CSRR) at the center. One way to achieve this is by constructing a rectangular patch with teeth or finger-shaped structures at all sides, which can improve the impedance matching and radiation characteristics of the antenna. In addition, a square shape can be cut at the center of the patch to create a CSRR as shown in Fig.4.6.

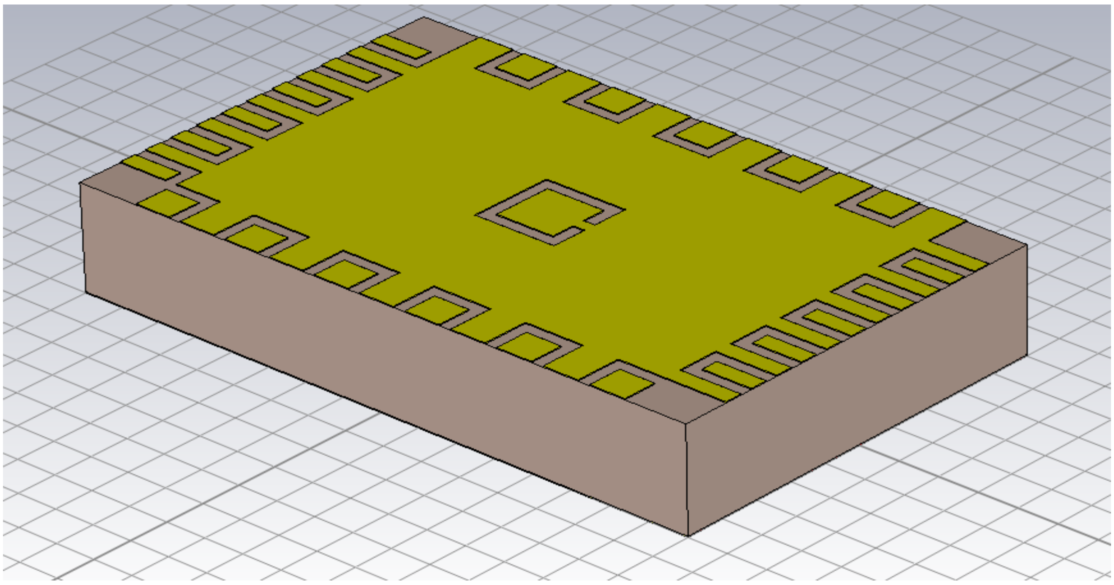


Fig.4.6.Patch On Substrate

To construct the proposed antenna, follow the below steps:

1.To begin with, the ground plane needs to be prepared for the unit cell. The ground plane is essentially a conductive sheet that serves as a reflector for the antenna.

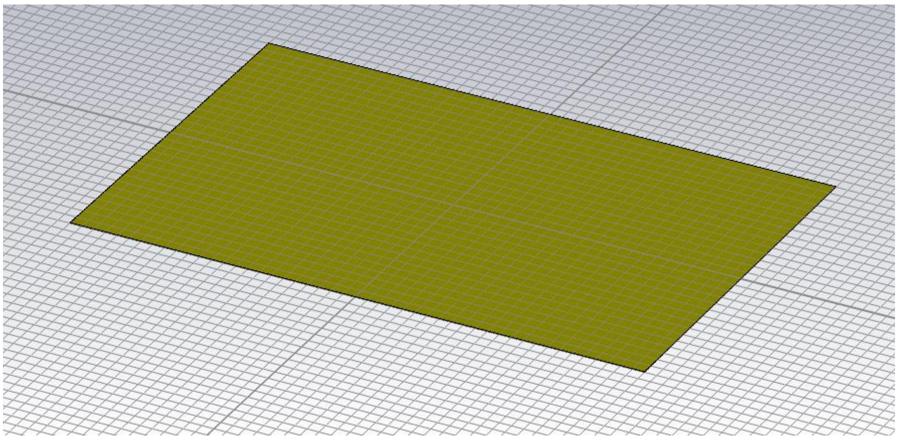


Fig.4.7.Ground Plane Of Proposed Antenna

2.After the ground plane is prepared, the next step in constructing a microstrip patch antenna is to cut the lower substrate. The substrate is a non-conductive material that provides separation between the patch and the ground plane.

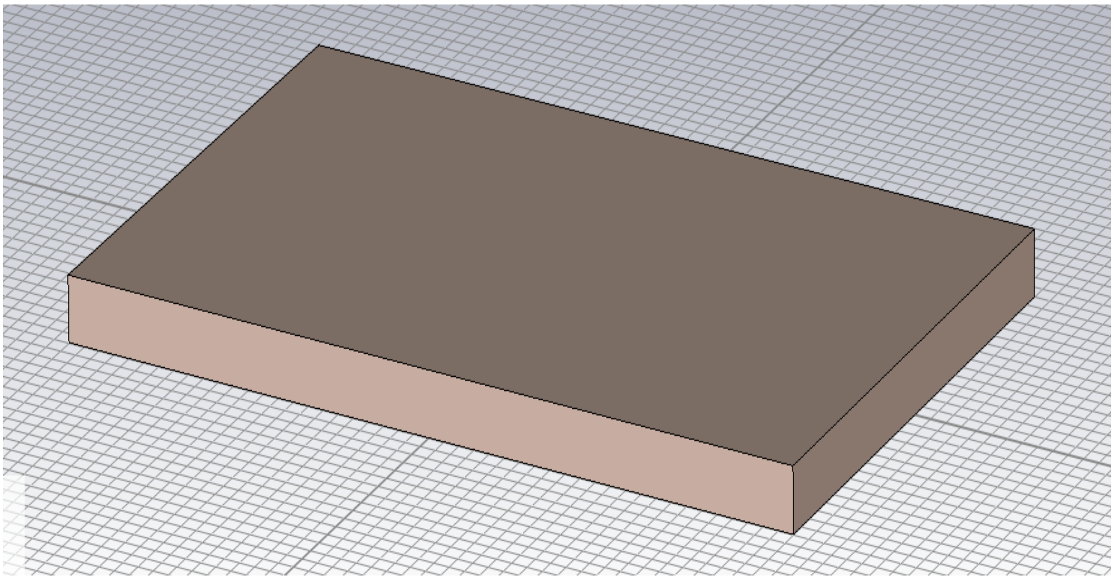


Fig.4.8.Lower Substrate Of Proposed Antenna

3.Attach the Patch: The patch is made of a conductive material such as copper and is cut into the desired shape and size.

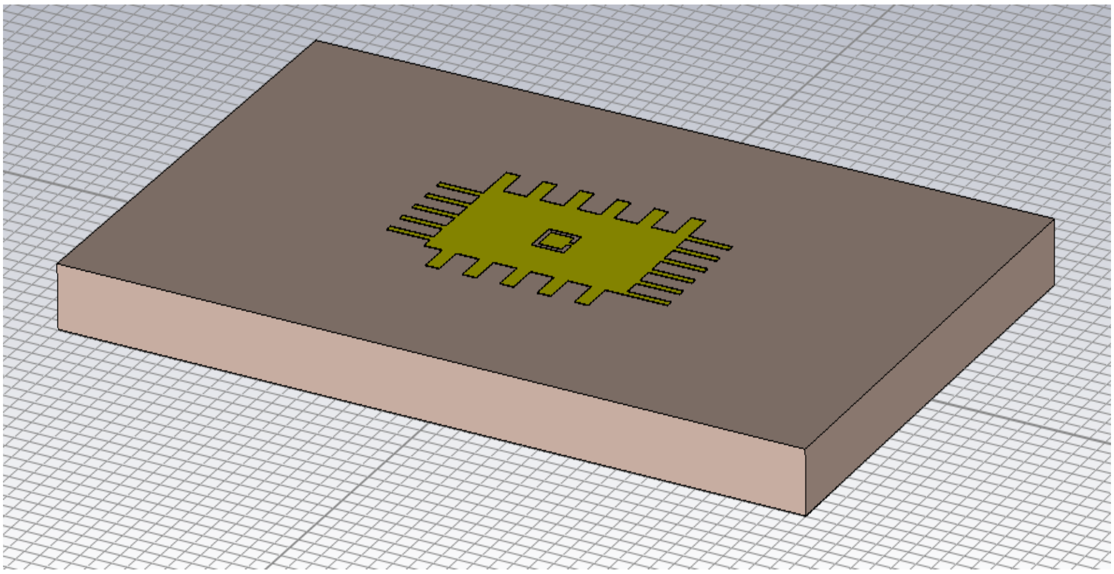


Fig.4.9.Single Unit Cell Patch On Lower Substrate

4.To increase the radiation efficiency and bandwidth of the antenna, the constructed patch can be replicated as a 3x3 array. This means that two additional copies of the patch are placed adjacent to the original patch, forming a 3x3 grid. This increases the total area of the patch, which in turn increases the radiation efficiency of the antenna.

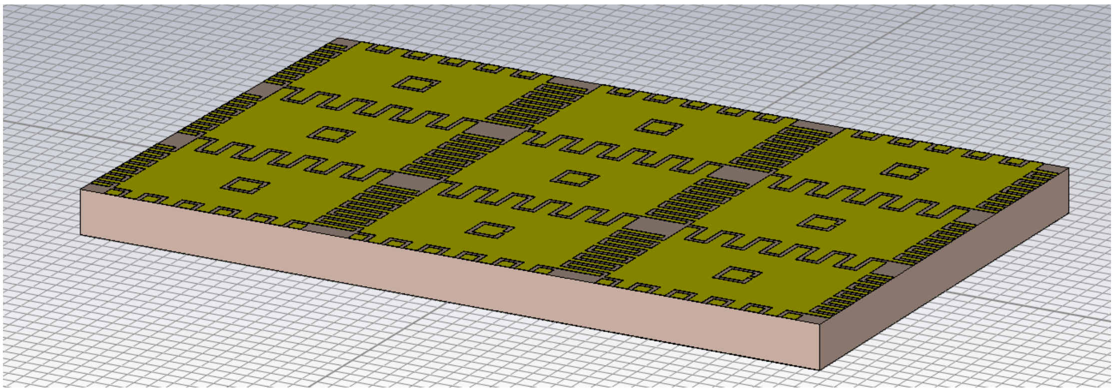


Fig.4.10.3x3 Patches On Lower Substrate

5.After the lower metasurface layer is prepared, the next step in constructing the proposed design is to cut the upper substrate.

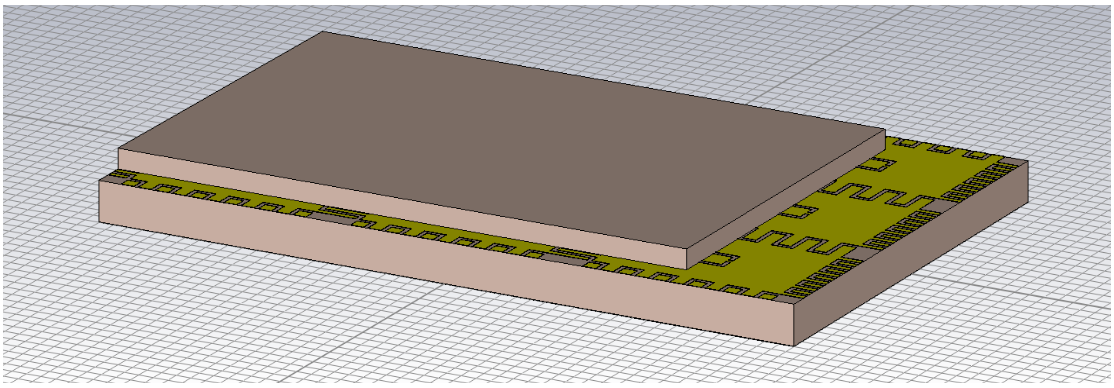


Fig.4.11.Upper Substrate Of Proposed Antenna

6. As the last step, place the rectangular patch on top of the upper substrate.

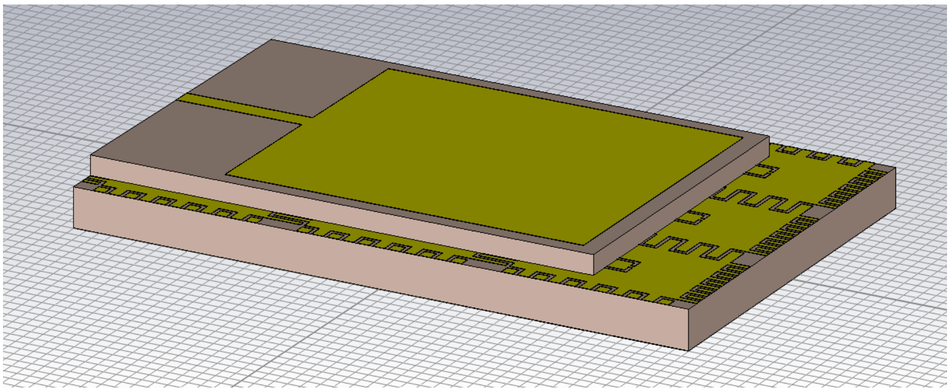


Fig.4.12.Rectangular Patch On Upper Substrate

4.2.3.Applications

1.In healthcare, the antenna can be integrated into wearable devices, such as smartwatches or fitness trackers, to enable reliable wireless communication between the device and a medical monitoring system. This can help doctors and caregivers monitor patient health and provide timely interventions when necessary.

2.In sports and fitness, the antenna can be used in wearable devices to enable wireless communication between the device and a coach or trainer. This can help athletes track their progress and receive real-time feedback to improve their performance.

3.In military and emergency services, the antenna can be integrated into wearable communication devices to enable reliable wireless communication between team members in the field. This can help improve coordination and response times in critical situations.

4.2.4.Conclusion

In conclusion, microstrip patch antennas, and specifically rectangular patch antennas, have become increasingly popular in modern communication systems due to their various advantages, including low profile, compact size, ease of integration with printed circuit boards, ability to operate at various frequencies, and low cost. The construction of these antennas can be done using electromagnetic simulation software, such as CST Microwave Studio, which allows for the optimization of the antenna's parameters and the analysis of its performance. This process involves starting with a rough estimate of the antenna's dimensions, optimizing its performance using simulation software, constructing the antenna using standard printed circuit board techniques, and analyzing its performance using the simulation software. Furthermore, microstrip patch antennas have a wide range of applications in various industries. In healthcare, they can be integrated into wearable devices to enable reliable wireless communication between the device and a medical monitoring system, helping doctors and caregivers monitor patient health and provide timely interventions. In sports and fitness, they can be used in wearable devices to enable wireless communication between the device and a coach or trainer, allowing athletes to track their progress and receive real-time feedback to improve their performance. In military and emergency services, they can be integrated into wearable communication devices to enable reliable wireless communication between team members in the field, improving coordination and response times in critical situations. Overall, microstrip patch antennas have proven to be a versatile and effective solution for a wide range of communication needs, and their continued use and development will likely lead to further innovation and advancements in the field.

CHAPTER 5

RESULTS

5.1 Analysis of S-parameters

The antenna design employs a unique geometry of stacked patches that allow for a wider bandwidth and better performance compared to traditional patch antennas. The design utilizes a fractal geometry with several iterations of patch elements, which provides a larger surface area for the radiating element and improves the antenna's directivity. The fractal geometry also reduces the overall size of the antenna, making it more compact and suitable for use in mobile devices. Extensive simulations were conducted to optimize the antenna's performance and determine the best dimensions for each iteration of the fractal geometry. The simulations were done using electromagnetic simulation software, which allowed for accurate prediction of the antenna's radiation characteristics. The results of the simulations were then used to fabricate a prototype antenna, which was tested in a controlled environment. The testing showed that the antenna has a wider bandwidth compared to traditional patch antennas and maintains good radiation characteristics across the frequency range. The radiation pattern of the antenna was found to be directional, which makes it suitable for point-to-point communication applications. The antenna also exhibited good impedance matching, which is important for efficient transfer of energy between the antenna and the transmitter/receiver circuitry. Overall, the design provides a promising solution for improving the performance of patch antennas, and its compact size and wide bandwidth make it an attractive option for mobile devices and other applications where space is limited.

The figures presented in the text show that the desired frequency and best S11 performance of the microstrip rectangular patch antenna design can be achieved by setting py to 10 mm in Fig. 5.1 and by setting px to 16 mm in Fig. 4=5.2. These values have been identified as the optimal dimensions that provide the best overall performance for the antenna design. By using these dimensions, the antenna can provide low return loss and enhanced efficiency within the desired frequency band. These findings are important for the practical implementation of the antenna design, as they allow for the precise tuning and customization of the antenna's properties to achieve the desired performance characteristics.

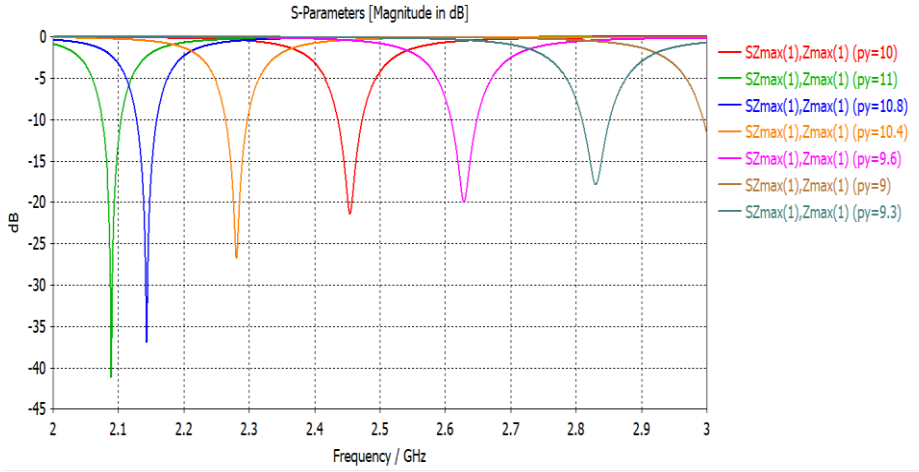


Fig. 5.1 S-parameters of Unit Cell for different values of "py"

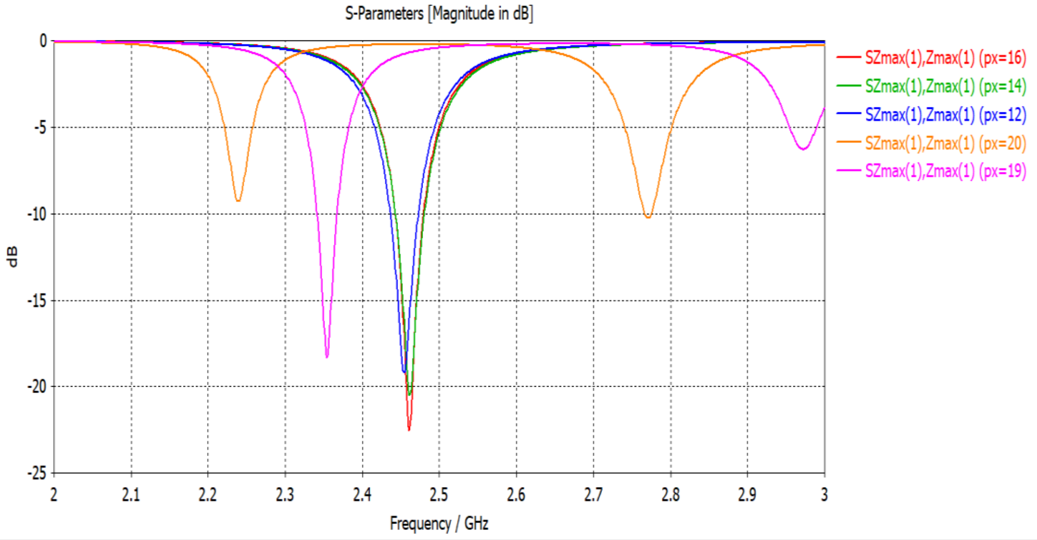


Fig. 5.2 S-parameters of Unit Cell for different values of "px"

5.2 S-parameters for designed antennas

The study includes three figures: Fig. 5.3 shows the S11 parameter of the microstrip patch antenna design, while Fig. 5.4 displays the S11 parameter of the unit cell design. These figures are useful for analyzing the antenna's performance and determining the optimal dimensions and configurations for low return loss and high efficiency within the desired frequency range.

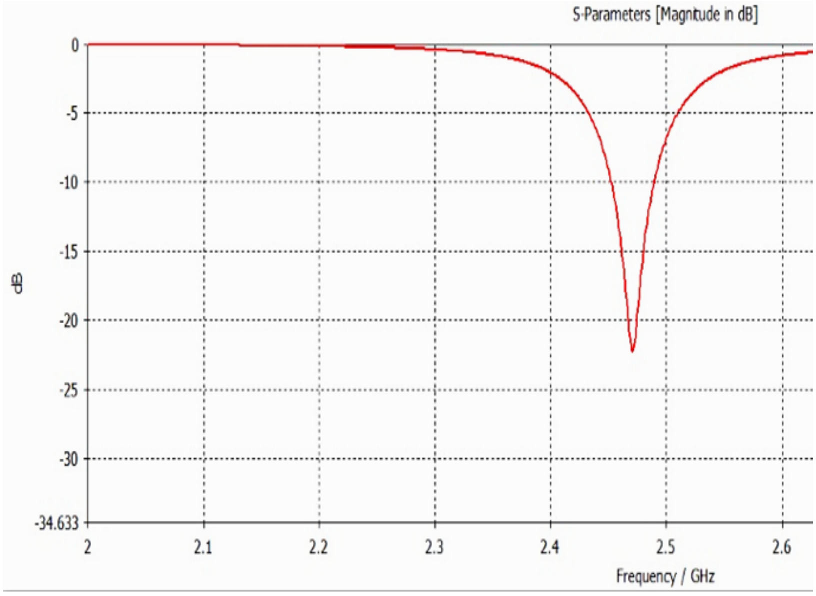


Fig. 5.3 S-parameters of Unit Cell

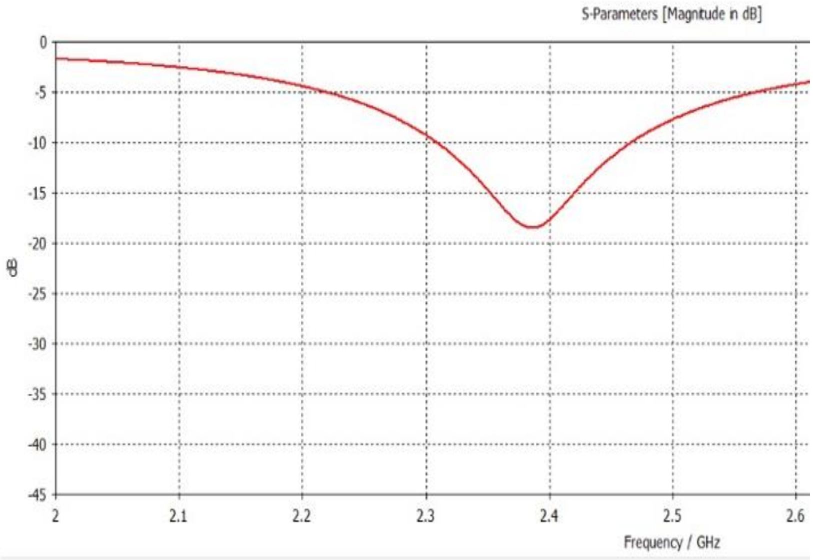


Fig. 5.4 S-Parameters of Rectangular Patch Antenna

Fig. 5.5 shows the S11 parameter of the microstrip patch antenna design with the addition of a metasurface layer for improved performance. These three figures provide a clear visual representation of the different antenna designs and their corresponding parameters, enabling a better understanding of the optimization process and the resulting performance improvements. The figures are helpful in identifying the optimal design configurations and dimensions, allowing for more precise tuning and customization of the antenna's properties to achieve desired performance characteristics.

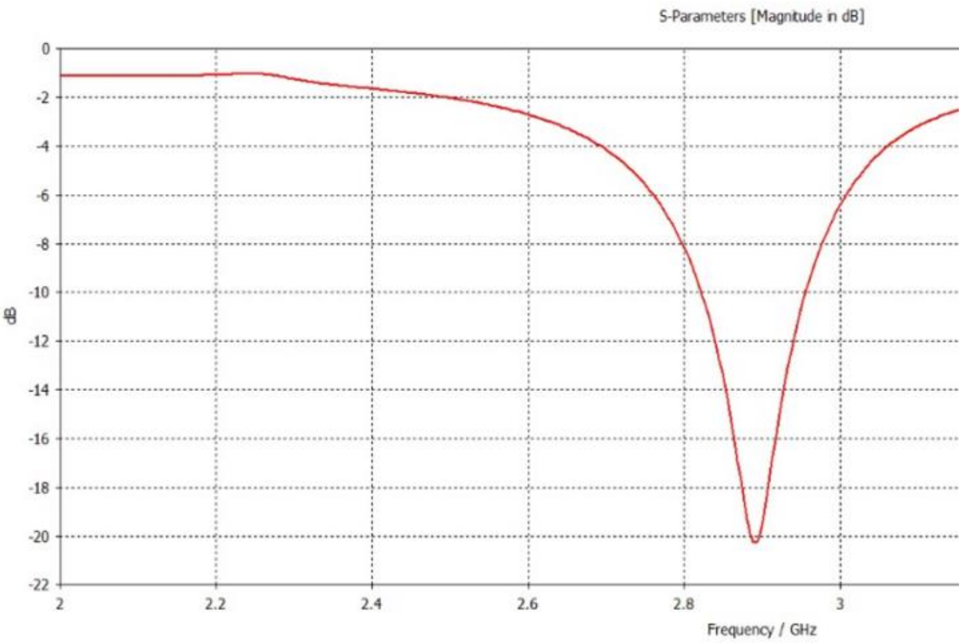


Fig. 5.5 S-Parameters of Rectangular Patch Antenna with metasurface

5.3 polar plots

Fig. 5.6 and Fig. 5.7 offer insights into the farfield radiation pattern of the antenna, showing how the gain changes in response to the elevation and azimuth angles. Fig. 5.6 demonstrates that the antenna has maximum gain when radiating in the direction of the horizon (at 0 degrees elevation angle), but its gain decreases as the elevation angle increases. Fig. 5.7 shows that the antenna has maximum gain when radiating directly in front of the antenna (at 0 degrees azimuth angle) but its gain diminishes as the azimuth angle increases. These plots demonstrate that while the antenna is not equally effective in all directions, it still provides significant gain at a wide range of angles, making it suitable for various applications. These plots are critical in helping antenna designers and engineers understand how the antenna will perform in different applications and scenarios.

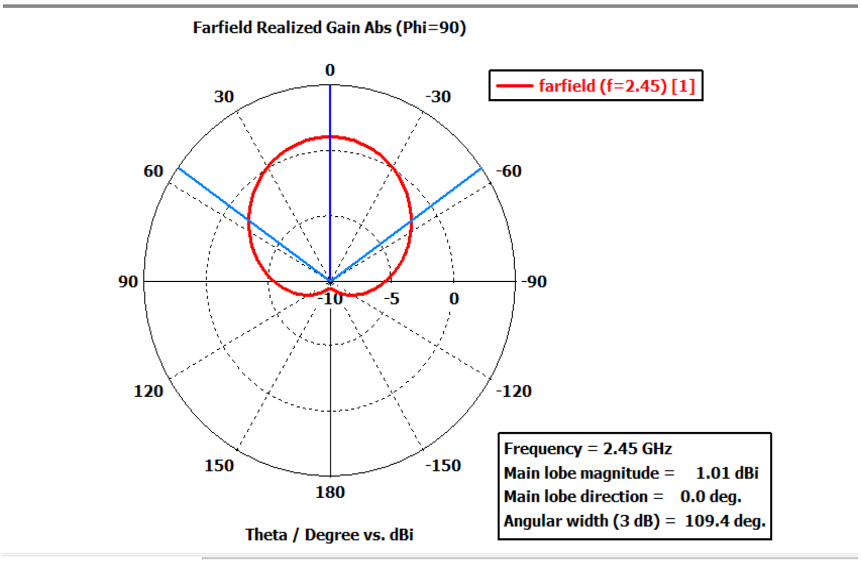


Fig. 5.6 Polar Plot of Farfield Realized Gain at Phi=90

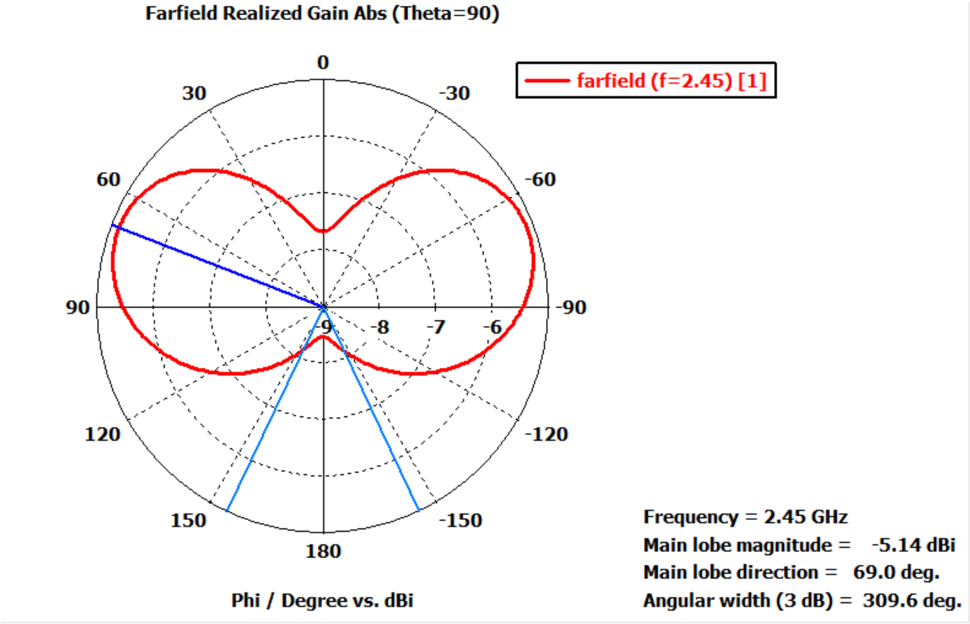
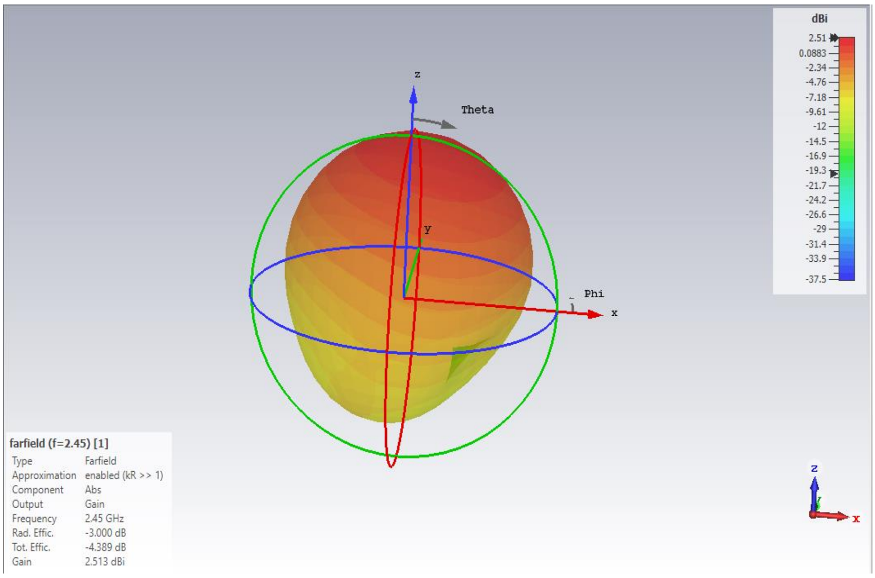


Fig. 5.7 Polar Plot of Farfield Realized Gain at Theta=90

5.4 Other Plots

Fig. 5.8 provides a detailed 3D farfield plot that illustrates the antenna's gain as a function of both elevation and azimuth angles, allowing for the identification of the optimal radiation direction and fine-tuning of the antenna's performance for specific applications.



farfield (f=2.45) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 2.45 GHz
Rad. Effic. -3.000 dB
Tot. Effic. -4.389 dB
Gain 2.513 dBi

Fig. 5.8 3D Farfield Plot of Gain

Meanwhile, Fig. 5.9 depicts the radiation efficiency, which represents the ratio of power radiated by the antenna to the total input power.

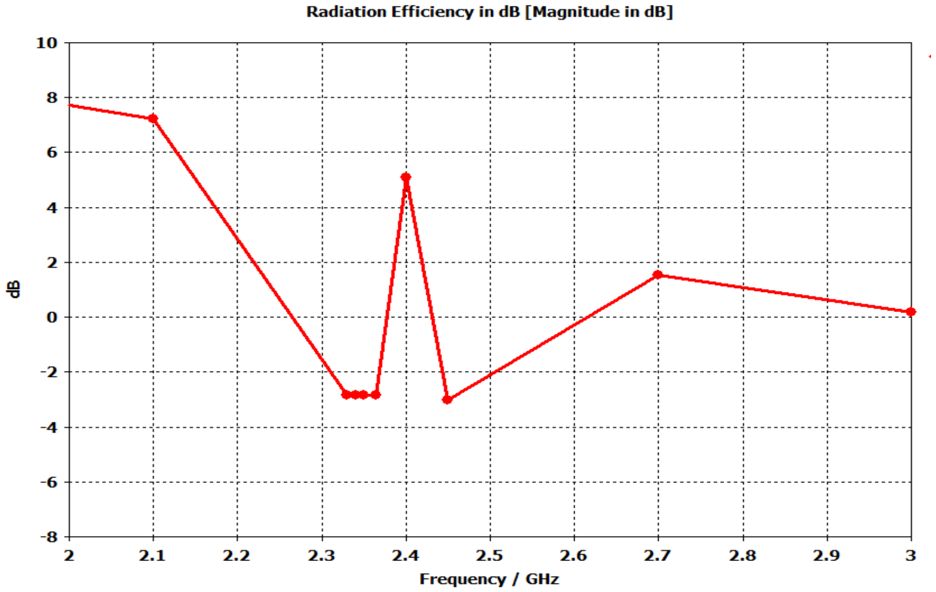


Fig. 5.9 Radiation Efficiency vs Frequency

Fig. 5.10 shows the antenna's total efficiency, taking into account losses due to impedance mismatches, radiation from other sources, and material absorption.

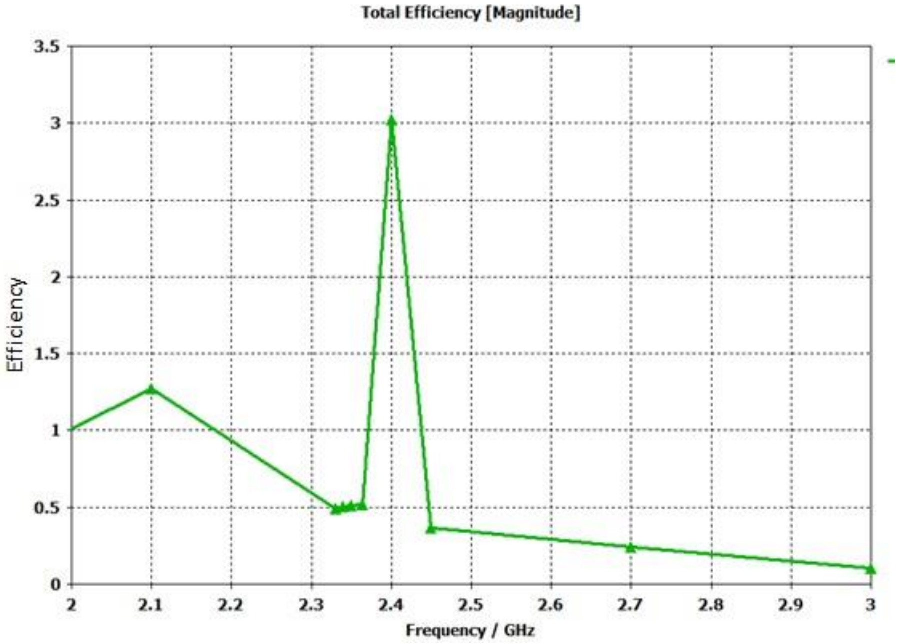


Fig. 5.10 Total Efficiency vs Frequency

Finally, Fig. 5.11 displays the antenna's gain as a function of frequency, providing essential information for communication and remote sensing applications. Together, these figures offer insights into the antenna's overall performance and are crucial for optimizing the design for specific applications.

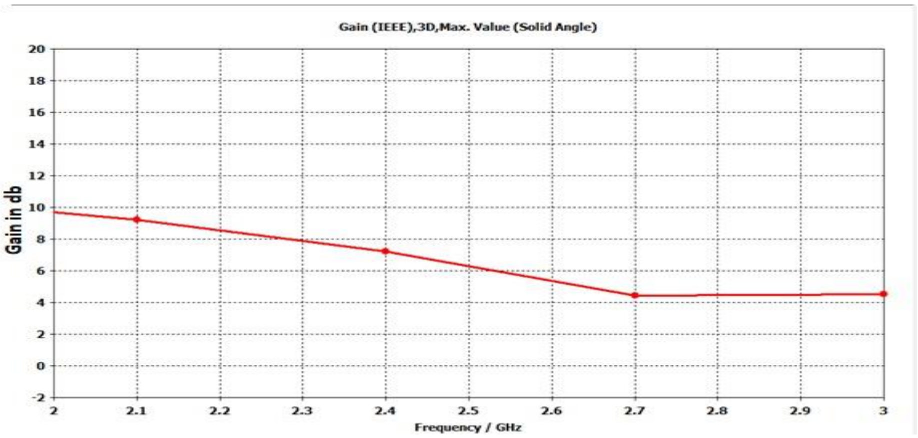


Fig. 5.11 Gain vs Frequency

TABLE 5.1: COMPARISON WITH LITERATURE

Ref	freq	gain	dimensions	Efficiency	material
A.S.M[1]	1Ghz	NA	5x5x7 cm2	NA	FR4
Z.H.Jiang [15]	1-6Ghz	>35dbi	3.6x.79 x.79	237.5 dB/GHz And 271.4 dB/GHz	Rogers RT And Duroid 5880
S.Yan[8]	2.45/5.6	2.09dbi	45 in diameter	NA	PCB Button, Felt/Shield PCB Module
Chen S. [37]	2.40/5.30	7.80/3.10 (Half-Wave)	40 × 40 Modular Button	NA	Cumming-foam-PF4/ ShieldIt
Chen S. [38]	4.75-5.25	NA	40 × 40 Modular Button	NA	Cumming-foam-PF4/ ShieldIt
Yan S. [5]	2.40	FS, OA 1.80/5.10	100 × 100 Circular Button	97.00/71.00	FR4, Felt /Copper, ShieldIt
Alomainy A. [39]	2.40	2.40	Dipole Sensor Antenna	28.00	FR4/Copper
Sabapathy T. [40]	2.40	3.00	GPS Tracking Antenna	NA	FR4/Copper
Simorangkir [41]	2.40/5.80	OB 4.16/4.34	70 (Diameter) Patch Antenna	58.6	PDMS/ShieldIt

M.El Atrash [7]	3.5/5.8	6.8 and 3.7	4×4 AMC array	78.2	Rogers ULTRALAM 3850 substrate
H.R.Raad [11]	2.45	4.8	M shaped Antenna	NA	NA
S.Velan [13]	GSM-1800/ISM-2.45	NA	50mmx50mmx1mm	NA	Jean Fabric
W.Liu [17]	5.5	9.9	3.25x10x9	5.7 GHz	RO4003C
T.Yue [19]	5.3	6.9	Stereo MS antenna l=33mm and w=13.5mm	NA	Rogers RO4003
This work	2.45	7.0	48x30		FR4

CONCLUSION

The paper presents a novel design of a compact wearable antenna for body-area network devices based on composite right/left-handed transmission line (CRLH-TL) metasurfaces. The proposed design utilizes metamaterials to manipulate electromagnetic waves and control the antenna's radiation pattern, resulting in significant improvements in the antenna's performance. The antenna design consists of a rectangular microstrip patch with dimensions of 48 x 30 mm2, which resonates at 2.45 GHz. The paper also investigates a modified version of the first design that incorporates a split-ring resonator (SRR) in the metasurface unit cell, resulting in a resonant frequency of 2.89 GHz, improving the bandwidth of the antenna. The study shows that the proposed antenna designs have high efficiency and wide bandwidth, with robust performance to structural deformation and human body loading. The use of metamaterials and metasurfaces in wearable antenna design offers several advantages over traditional antenna designs, including improved impedance matching, enhanced radiation efficiency, and a smaller form factor. The proposed antenna designs based on composite right/left-handed transmission line (CRLH-TL) metasurfaces offer a promising solution to the challenge of developing compact and efficient wearable antennas for the advancement of wearable technology and wireless communication systems.

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***Abstract*— The purpose of this study is to present a new type of wearable antennas that are based on Composite Right Left Handed Transmission Line (CRLH-TL) metasurfaces. The metasurfaces are tailored for use in wearable medical devices, using a printed coplanar waveguide (CPW) as the feed structure. The metasurface serves as both the ground plane for isolation and the main radiator, with the aim of achieving low SAR and improving upon the narrowband characteristics of microstrip antennas. The study investigates two antenna geometries, with the first design resonating at 2.89 GHz, and exhibiting high efficiency and wide bandwidth, despite being robust to structural deformation and human body loading. These antennas are suitable for use in Wearable Medical Body-Area Network Devices and Wireless Body Area Networks (WBAN's), with the results obtained by simulating the designs in the CST suite.**

Keywords—CRLH-TL, Metasurface, Body-Area Network

1. INTRODUCTION

A Wireless Body Area Network (WBAN) is a type of wireless network consisting of small, low-power sensors that monitor physiological parameters such as heart rate, blood pressure, and temperature, and transmit data wirelessly to a central monitoring device[1],[2],[5]. WBANs have various applications, including healthcare, sports and fitness, and military and emergency services. Designing a WBAN is challenging due to size, power consumption, and wireless communication constraints, and there are also challenges associated with security, privacy, and data management.

Recent research has focused on wearable antenna designs using metamaterials[3],[7],[17],[22]. Metamaterials are substances with artificially created structure that possess electromagnetic properties that are not found in nature. Metasurfaces and Composite Right/Left-Handed Transmission Lines (CRLH TL) are two commonly used metamaterials when designing wearable antennas. CRLH TL models exhibit both left-handed (LH) and right-handed (RH) behavior, allowing for the propagation of waves with negative phase velocity, which has interesting applications in metamaterials and antennas with unusual properties. The usage of CRLH TL models in microwave and millimeter-wave circuits provides low-loss transmission and reflection properties over a wide frequency range[11].

To address the need for efficient and reliable antennas in compact and portable devices, a novel design of a rectangular microstrip patch antenna incorporating a meta surface unit cell 3x3 array has been proposed[9]. The design utilizes the unique properties of metamaterials to manipulate electromagnetic waves and control the antenna's radiation pattern, resulting in improved impedance matching and radiation efficiency. This design is ideal for wearable communication systems and has important implications for the development of wearable technology in healthcare, sports and fitness, and military and emergency services. The use of metamaterials in wearable antenna design offers a promising avenue for future research.

2. ANTENNA DESIGN

2.1 Antenna Configuration

The features like compact size, low profile, and ease of integration with other electronic components makes the wide usage of microstrip patch antenna in today's world. Among the different types of microstrip patch antennas, the rectangular microstrip patch antenna is particularly popular due to its specific advantages in size, weight, and ease of integration, as well as its wide range of applications, including wireless communication systems, satellite communications, and radar systems. One of the main advantages of rectangular patches is their ease of design and fabrication, as well as their ability to be easily integrated with other components. Additionally, rectangular patches have a wider impedance bandwidth, which allows them to operate over a larger

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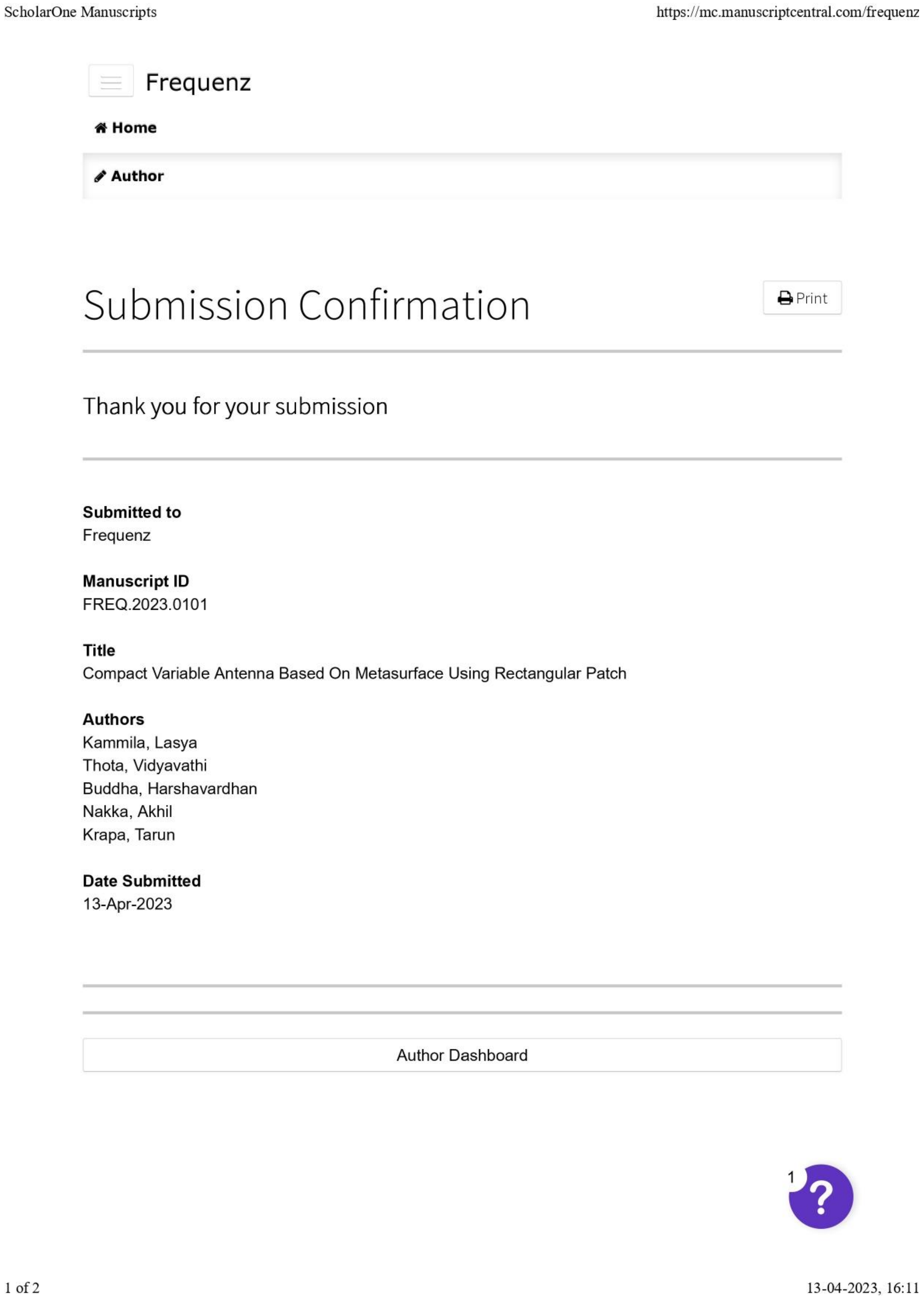

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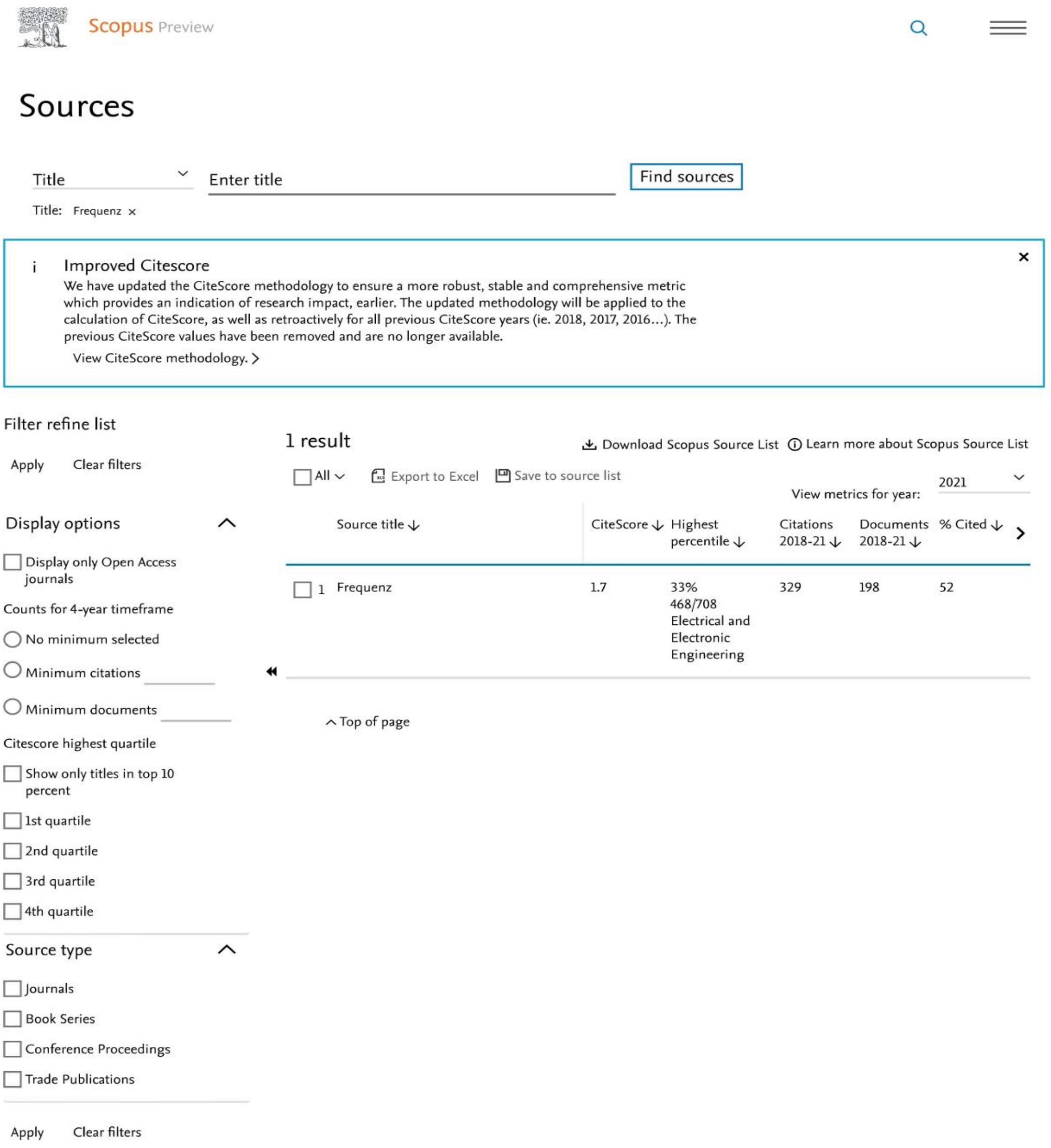

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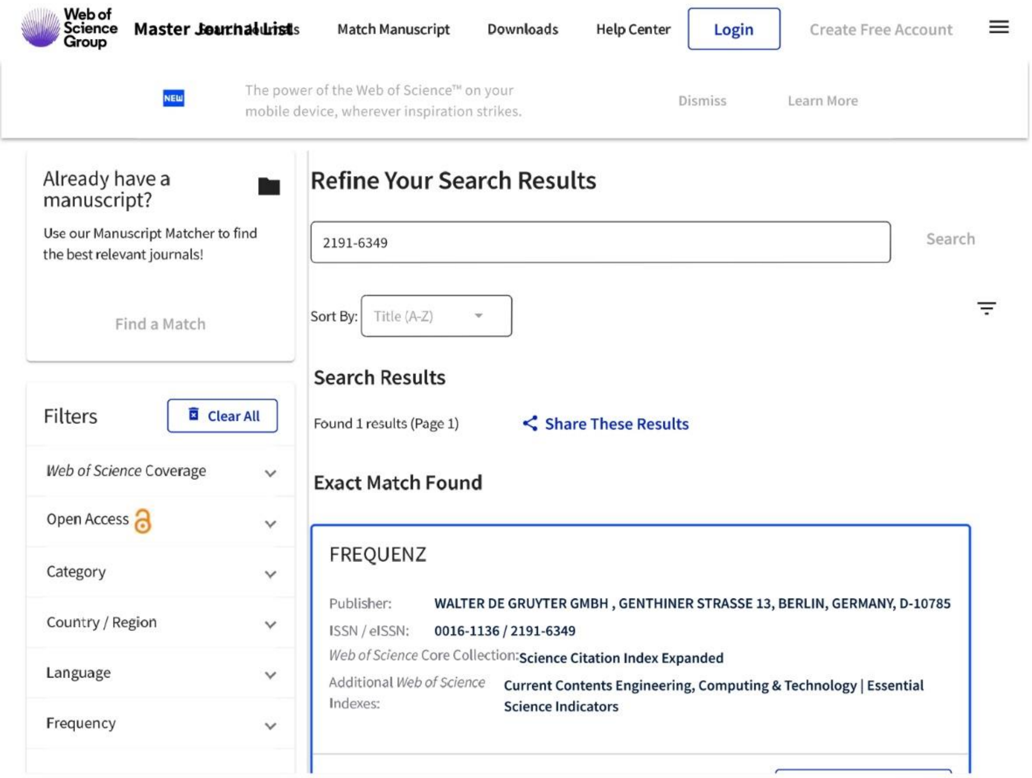

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