Design and Analysis of Archimedean Spiral Absorber for High-Frequency Microwave Applications

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OF
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IN
PHYSICS

Submitted by:

Aastitva
(2K21/MSCPHY/01)

Avaneesh Kumar Mishra
(2K21/MSCPHY/09)

Under the supervision of

Dr. Yogita Kalra & Dr. Kamal Kishor

DEPARTMENT OF APPLIED PHYSICS
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042
MAY, 2023

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We hereby certify that the work, which is presented in Dissertation-II entitled "**Design and Analysis of Archimedean Spiral Absorber for High-Frequency Microwave Applications**" fulfillment of the requirement for the award of the Degree of Master in Science in Physics and submitted to the Department of Applied Physics, Delhi Technological University, Delhi is an authentic record of our own, carried out during a period from January to May 2023, under the supervision of **Dr. Yogita Kalra** and **Dr. Kamal Kishor.**

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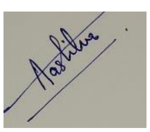

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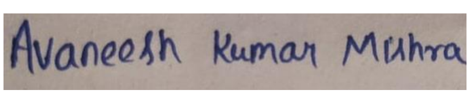

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Project Supervisor
Dr. Kamal Kishor

Assistant Professor
Department of Applied Physics
Delhi Technological University
Delhi- 110042

Project Supervisor
Dr. Yogita Kalra

Assistant Professor
Department of Applied Physics
Delhi Technological University
Delhi- 110042

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Place: Delhi **Aastitva (2K21/MSCPHY/01)**

Date: 28th May 2023 **Avaneesh Kumar Mishra (2K21/MSCPHY/09)**

ABSTRACT

We have examined the effectiveness of a two-arm Archimedean spiral as an absorber for high-frequency microwave applications. The reported absorber consists of a copper-based two-arm Archimedean spiral structure on an FR-4 dielectric substrate with a metallic ground plane. The design and optimization of the proposed structure have been done with the Finite Element Method (FEM) using COMSOL Multiphysics Simulation Tools. The geometrical parameters of the structure have been optimized to achieve 99% absorption in the frequency range of 150-200 GHz. The proposed absorber has potential application in reducing electromagnetic interference in various electronic devices, such as radars and wireless- communication.

Keywords: Archimedean spiral, Absorber, Microwave.

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LIST OF SYMBOLS/ABBREVIATIONS

$\mathbf{S_{11}}$ = Reflection coefficient

$\mathbf{S_{21}}$ = Transmission coefficient

ε = permittivity

μ = permeability

t = Thickness of metamaterial

r = radius of Archimedean spiral

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

A material, in its broadest sense, is any substance that can be used to construct or make something. The significance of the contents cannot be overstated. They evaluate how well, how long, and how functional goods in a number of industries operate, such as engineering, construction, medical, electronics, and transportation. Throughout history, the development and application of new materials have been a driving force behind technological advances. Materials research and engineering breakthroughs have resulted in biocompatible materials for use in medicine, flexible electronics, lightweight and strong metals, and enhanced composites. now we will introduce a new type of material which is called metamaterials.

There are certain materials that are periodically arranged that can manipulate electromagnetic radiation such types of materials are called "**metamaterials**."

1.2 History of Metamaterials

Sir Victor Veselago initially put up a theoretical idea of a totally different type of material having opposing physical properties with a negative refractive index. In 1967 Dr. Smith and his colleagues at the University of California develop the first metamaterial in the year 2000, which can bend electromagnetic waves**.**

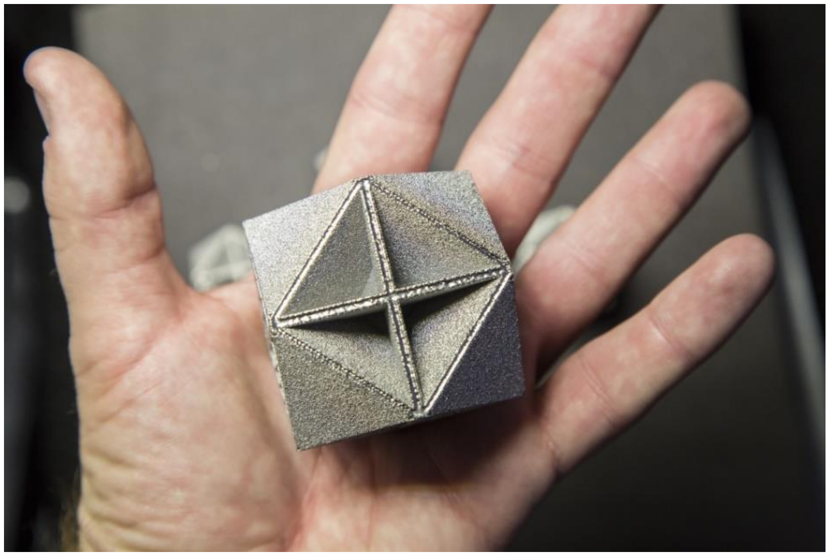

Fig 1.1: structure of the metamaterial

The properties of metamaterial, which is an artificial material or synthetic composite made by combining several elements like metal and plastic, are derived from its structure rather than its constituent parts [1]. A material that contains periodic, macroscopic structures to produce a desired electromagnetic response is known as a "metamaterial”. When artificially manufactured inclusions are embedded in a particular media, we can design and control the metamaterials' properties to create them. This gives the designer access to a vast array of independent parameters, which contributes to the substantial improvement of the field of research. The word "meta" is a Greek word that means "beyond." "Metamaterials" possesses exotic qualities beyond naturally occurring materials. These are the materials that derive their properties not from the substance they are made of but rather from their structure. The reason they resemble genuine crystals is that they are made up of unit cells with a side length that are organized in a regular pattern, like squares. The small metallic resonators that make up the unit cells interact with an outside electromagnetic wave with a wavelength rather than actual atoms or molecules. Thus, it is possible to cause the electromagnetic properties of the medium to enter quite uncommon domains, such as one where both the electric permittivity and the magnetic permeability simultaneously turn negative (in the same frequency zone) [2]. These electromagnetic properties of a metamaterial depend on how the input light wave interacts with these metallic "meta-atoms”. A metamaterial is an arrangement of artificial structures intended to produce beneficial and unique electromagnetic characteristics. Metamaterials have a designability advantage over their conventional equivalents. Due to their specialized dielectric properties, metamaterials provide a new perspective on materials and an enormous amount of flexibility in material design. In an effort to regulate and alter electromagnetic wave behavior in ways that were previously unthinkable, metamaterials represent a novel approach to designing materials. They are made to display characteristics that are not seen in nature, such as a negative refractive index, hiding abilities, excellent absorption, and exceptional transmission. Instead of just depending on the chemical structure or atomic configuration present in conventional materials, these special properties are a result of the interaction of the subwavelength elements of the metamaterial. The ability to manipulate waves' interactions with subwavelength characteristics is the fundamental idea underlying metamaterials. These characteristics often take the form of elements or structures that are considerably smaller than the wavelengths of the waves they interact with. Metamaterials can acquire extraordinary qualities that are not possible with naturally occurring materials by carefully planning and arranging these subwavelength components. It was also shown that an array of split-ring resonators might be used to produce negative magnetic permeability [3]. The limits of materials science are continuously being redefined by the creation of metamaterials. These materials, with their tailored properties and their tunability to external stimuli, provide significant design flexibility in the area of electromagnetic research and beyond. In this brief review, we will describe the basic properties of (negative-refractive-index) metamaterials, as well as how their constituent parts (meta-atoms) can be created. We will succinctly describe one example of a use for such a medium, which is the blocking of light. Finally, we draw a line around the major issues that must be resolved before the use of metamaterials in these applications becomes more effective and functional. Artificial structures known as negative index materials (NIM) have refractive indices for light that are negative across a certain frequency range. This is only possible with artificial structures known as metamaterials because it does not occur in any known natural materials. Arrays of wires and cut-ring structures are the most common components of metamaterials that exhibit a negative refractive index for light; these media also exhibit a negative electrical permittivity and magnetic permeability.

1.3 Classification of Metamaterial

The system response to the presence of an electromagnetic field is dependent on the properties of the materials involved. By specifying macroscopic parameters permittivity Ɛ and permeability µ of the materials, these properties are characterized as below in Fig 1.2

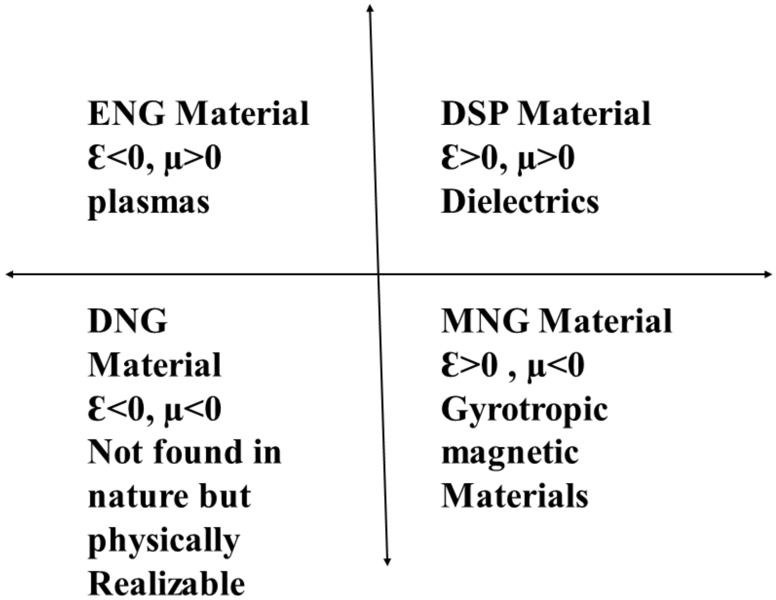

Fig 1.2: Classification of Metamaterials

- DPS (Double Positive Medium): Double positive (DPS) media are defined as those that have permittivity and permeability values both greater than zero ($\varepsilon > 0$, $\mu > 0$). This description applies to the majority of naturally occurring media (like dielectrics).
- ENG (Epsilon Negative Medium): Epsilon negative (ENG) mediums are defined as permittivity less than zero and permeability greater than zero ($\varepsilon < 0$, $\mu > 0$). Many plasma displays the features at specific frequencies.
- DNG (Double Negative Medium): A medium is referred to as a Double Negative (DNG) medium if its permittivity and permeability are both less than zero ($\varepsilon<0$, $\mu<0$). Only artificial creations have been used to demonstrate this class of materials.

- MNG (Mu Negative Medium): Mu negative (MNG) media are defined as having a permittivity larger than 0 and a permeability less than 0 (Ɛ> 0, μ<0). This property is present in some gyro tropic materials in particular frequency regimes [4].

1.4 Different types of Metamaterials

1.4.1 Electromagnetic Metamaterial

Metamaterials is a new field of study within physics and electromagnetism. Applications involving optical and microwave technology use such structures. The following are more classes that are separated up for this kind of metamaterial.

1.4.1.1 Negative Index Metamaterials

Because both the permittivity and permeability are negative, the negative index metamaterial (NIM), also known as double negative metamaterial (DNG), has a negative index of refraction. Backward wave media is another name for negative index metamaterial and is formed if both and are negative.

1.4.1.2 Single Negative Metamaterials (SNW)

The relative permittivity or the relative permeability is negative in single negative metamaterials (SNM), but not both. Epsilon and Mu negative media are under the SNM category. Epsilon negative media (ENG) exhibit negative relative permittivity and positive relative permeability, whereas Mu negative media (MNG) exhibit the opposite. In order to conduct wave reflection studies, a slab of ENG material and a slab of MNG material are bonded. As a result, characteristics like resonances, anomalous tunneling, transparency, and zero reflection were demonstrated.

1.4.1.3 Electromagnetic Bandgap Metamaterials

EBG metamaterials, also known as left-handed metamaterials or photonic crystals, are used to control light. The creation of high-quality, low-loss dielectric structures is EBG's aim. Both classes are capable of allowing light to go in predetermined, desired directions.

1.4.1.4 Double Positive Metamaterials

Both the permittivity as well as permeability is positive in double-positive metamaterials (DPS) and forward wave propagation.

1.4.1.5 Bi-isotropic and Bi-anisotropic Metamaterials

Magnetoelectric coupling is used to demonstrate bi-isotropic media. The standard assumption is that the metamaterial exhibits separate electric as well as magnetic responses that are characterized by the parameters. many types of electromagnetic metamaterials, a magnetic field produces an electrical polarization, which is known as magnetoelectric coupling, and the electric field creates a magnetic polarization. Additionally known as bi-anisotropic

1.4.2 Chiral metamaterials

The metamaterial is referred to as chiral when it built from chiral components. An effective parameter K is not zero in chiral. Negative refraction will be achieved in metamaterials having strong chirality and positive, as shown by the wave propagation characteristics of a chiral metamaterial.

1.4.3 Metamaterial Type Based on Frequency Band

This kind operates within the specified frequency range. frequency-based metamaterials for surfaces FSS metamaterial allows signals that were blocked in one waveband to pass in another. It developed into a substitute for fixed-frequency metamaterials.

1.4.3.1 Photonic Metamaterials

It engages with optical wavelengths in this way. The photonic metamaterial can be distinguished from photonic band gap structures by its subwavelength period.

1.4.3.2 Tunable Metamaterials

The frequency changes in the refractive index can be freely adjusted in tunable metamaterials.

1.4.3.3 Terahertz Metamaterials

Between 0.1 and 10 THz, this metamaterial interacts with terahertz waves. This is equivalent to wavelengths in the far-infrared light spectrum between 0.03 mm and 3 mm (the long-wavelength edge of the EHF band).

1.4.4 Plasmonic Metamaterials

Surface plasmons, which is created by the interaction of light and metal dielectrics and are used by plasmonic metamaterials.

1.4.5 Acoustic Metamaterials

Acoustic metamaterials can regulate, direct, and modify the sound in any media, including gases, liquids, and solids, whether it takes the form of sonic, infrasonic, or ultrasonic waves. Additionally, a sonic wave may show negative refraction.

1.4.5.1 Nonlinear Metamaterials

Non-linear media, whose characteristics vary depending on the strength of the incident wave, can also aid in the formation of metamaterials. Non-linear optics need this kind of medium.

1.4.5.2 Elastic Metamaterials

Mechanical metamaterials are another name for elastic metamaterials. These metamaterials employ various parameters to produce a negative index of refraction in non-electromagnetic materials. There has been a novel design which has elastic metamaterials that can function as either liquids or solids.

CHAPTER 2

APPLICATION OF METAMATERIALS

Metamaterials are engineered materials that exhibit properties not found in natural materials [5]. They are designed to have unique electromagnetic, acoustic, or thermal properties, which enable a wide range of applications across various fields. Here are some notable applications of metamaterials:

2.1. Acoustic and Vibration Control

In order to reduce the undesirable and negative consequences brought on by unavoidable vibrations and noises, vibration and sound management is crucial and vital to many engineering applications. Due to its unique characteristics, such as negative and fluctuating Poisson's ratios, nonlinear force-displacement relationships, bi- or multi-stable states, the capacity to absorb or reflect sound, and other qualities, the use of metamaterials and origami-based structures for vibration control and sound abatement has received increasing interest [6]. By manipulating sound waves and vibrations, metamaterials can be used for noise cancellation, soundproofing, and vibration isolation.

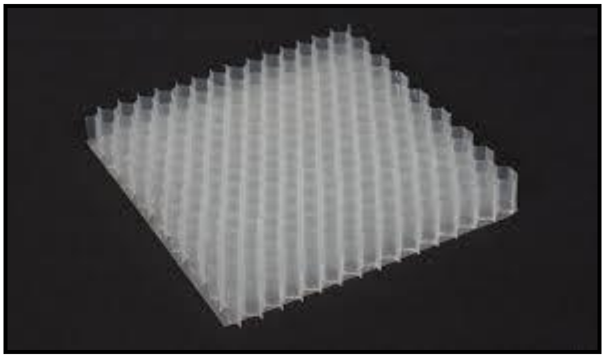

Fig 2.1: Honeycomb acoustic structure metamaterial

They can be used to produce substances that have an acoustic refractive index that is negative or zero, allowing sound waves to be suppressed or redirected. To reduce structural vibration and absorb impact energy, honeycomb structures are widely used in lightweight sandwich panels and cellular constructions. Due to their superior impact energy absorption capabilities and capacity for volume change control, auxetic honeycomb structures are appealing for a variety of technical applications.

2.2. Antennas and Wireless Communication

The design and functionality of antennas have been revolutionized by metamaterials, resulting in improvements in wireless communication systems. Engineers have been able to produce antennas with improved performance characteristics by modifying the electromagnetic properties of metamaterials.

The ability of metamaterial-based antennas to achieve compactness and miniaturization while keeping high efficiency is one of its fundamental advantages [7]. Traditional antennas frequently need to be quite large to function at particular frequencies, which prevents their integration into compact devices. Metamaterials, however, make it possible to build smaller antennas with desirable performance metrics and good radiation efficiency.

Additionally, metamaterials provide better frequency selectivity and directivity. These designed materials can modify an antenna's emission pattern, enhancing gain in particular directions. Antennas can be made to broadcast or receive signals more successfully in specific directions by adjusting the metamaterial structure's characteristics, which enhances the signal's quality and range.

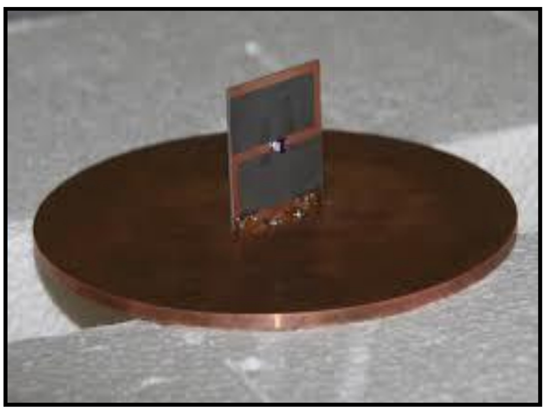

Fig 2.2: Design of metamaterial antena.

Applications for metamaterial-based antennas can be found in cutting-edge wireless technologies. For instance, metamaterials have special prospects in the realm of millimeter-wave and terahertz communications, where conventional antenna designs encounter difficulties as a result of shorter wavelengths. They make it possible to create high-gain, directed antennas that effectively operate at these high frequencies, facilitating the development of current and upcoming high-speed wireless networks.

2.3 Thermal management

Metamaterials have emerged as viable methods for increasing heat transport and managing thermal characteristics, which is a crucial component of many contemporary technologies.

Thermal management has advanced as a result of the increased capabilities for manipulating and controlling heat transmission given by metamaterials. By providing particular thermal qualities that may be tailored to specific applications, these specifically engineered materials provide more effective heat dissipation and insulation.

The ability of metamaterials to exhibit negative thermal expansion coefficients makes thermal management one of their principal uses. Metamaterials, unlike other substances, can contract in response to temperature changes. This property allows them to withstand the expansion of neighboring materials, which can cause difficulties such as heat stress and mechanical failure. By adding metamaterials into structures or electronics, thermal expansion mismatch can be decreased, boosting reliability and lifetime.

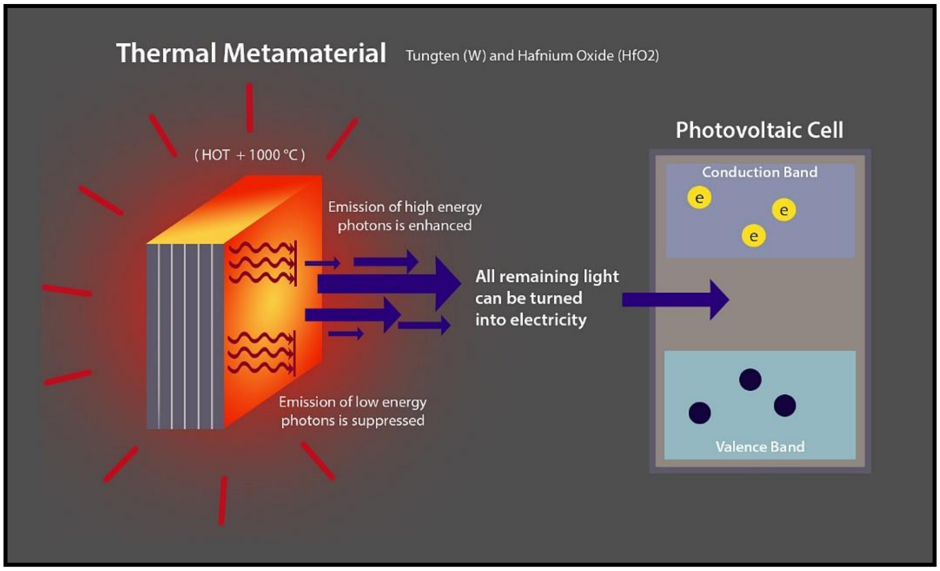

Fig 2.3: Thermal metamaterial and it’s one of the working applications.

Furthermore, metamaterials with high heat conductivity can be developed. When compared to normal materials, some metamaterial constructions can have better thermal conductivity. Thermal energy can be more effectively carried and dissipated by incorporating these materials into heat transfer routes, such as heat sinks or heat spreaders. This is especially advantageous for applications requiring effective cooling, such as electronic equipment, power electronics, and high-power lasers.

Finally, metamaterials offer exciting potential for thermal management. Their particular thermal properties, which include negative thermal expansion, improved thermal conductivity, and great thermal insulation, enable better heat dissipation, less thermal stress, and more effective energy conversion. As metamaterials research and development advances, we may expect to see more advancements in heat management solutions across a variety of industries.

CHAPTER 3

METAMATERIAL PARAMETERS

3.1 Electric and Magnetic Field Response

Electromagnetic field, a physical phenomenon that arises in space from changing electric charges over time and symbolizes the interaction of magnetic and electric fields. In contrast to static charges, which will only create static electric fields in space. One of the reasons for time-varying electric charges is the time-varying electric field that the magnetic fields produce. Four differential equations that express the time-varying Maxwell's equations provide a description of this.

$$\boldsymbol{\nabla}.\ \boldsymbol{E} = \boldsymbol{\rho_v(t)}/\boldsymbol{\varepsilon} \qquad 3.1.1$$

$$\boldsymbol{\nabla}.\ \boldsymbol{B} = \boldsymbol{0} \qquad 3.1.2$$

$$\boldsymbol{\nabla} \times \boldsymbol{E} = -\boldsymbol{\mu}\ \frac{\partial H}{\partial t} \qquad 3.1.3$$

$$\boldsymbol{\nabla} \times \boldsymbol{B} = \boldsymbol{J}(\boldsymbol{t}) + \boldsymbol{\varepsilon}\frac{\partial E}{\partial t} \qquad 3.1.4$$

Here, $\boldsymbol{\rho_v}$ = charge density of time-varying volume

$\boldsymbol{\varepsilon}$ = Relative Electric permittivity

$\boldsymbol{\mu}$ = Relative Magnetic permeability

$\boldsymbol{J}$ = Electric current density in a material that varies over time D & B denote the flux densities of the electric and magnetic fields, respectively.

E & H stand for the intensity of magnetic and electric fields that change over time, respectively.

In 1865, James Maxwell created equations. explaining that electromagnetic radiation is produced by magnetic fields and oscillating electric fields and that the speed of these radiations is equal to the speed of light in empty space, from (3.1 1) to (3.1 4). The curl of Equations (3.1) 3 and (3.1) 4 can be used to explain electromagnetic wave propagation equally well. Two key elements, usually referred to as constitutive parameters, impact the features and behavior of an electromagnetic wave in a material in addition to conductivity. They are magnetic permeability and electric permittivity. To put it another way, when combined with the medium's boundary conditions, the aforementioned properties determine the medium's response to an incoming electromagnetic wave. The following two equations represent the relationships between the electric and magnetic field variables in an elementary linear and isotropic medium.

$$\boldsymbol{D} = \boldsymbol{\varepsilon E} \qquad (3.1\ 5)$$

$$\boldsymbol{B} = \boldsymbol{\mu H} \qquad (3.1.6)$$

In Eqs. (3.1 5) and (3.1 6), each is often complex and frequency-based in a lossy dispersive medium and the real quantity isn't in the lossless isotropic medium. Refractive index, n, wavenumber, and k are some significant parameters that can be calculated using Eqs. (3.1 1)–(3.1 6), which are provided as

$$\boldsymbol{k} = \boldsymbol{\omega}\sqrt{\boldsymbol{\mu\varepsilon}} \qquad (3.1\ 7)$$

$$\boldsymbol{\eta} = \sqrt{\boldsymbol{\mu\varepsilon}} \qquad (3.1\ 8)$$

$$\boldsymbol{n} = \sqrt{\boldsymbol{\mu_r \varepsilon_r}} \qquad (3.1\ 9)$$

Were, $\boldsymbol{\omega} = \boldsymbol{2\pi f}$ defines radial frequency (in rad/sec), f is the frequency in Hz

$\boldsymbol{\mu_r} = \boldsymbol{\mu}/\boldsymbol{\mu_0}$ and $\boldsymbol{\varepsilon_r} = \boldsymbol{\varepsilon}/\boldsymbol{\varepsilon_0}$ define relative permeability and permittivity.

3.2 Negative Refractive Index (NRIs)

Victor Veselago initially discussed NRIs in 1967, demonstrating that it is feasible to reverse the direction of phase velocity in the antiparallel direction to the pointing vector. These NRI metamaterials are sometimes referred to as left-handed metamaterials. In the year 2000, John Pendry discovered an efficient method for using left-handed metamaterials, which will enable the EM wave's phase velocity to propagate against the group velocity by aligning a metallic wire along the wave's direction, resulting in negative permittivity.

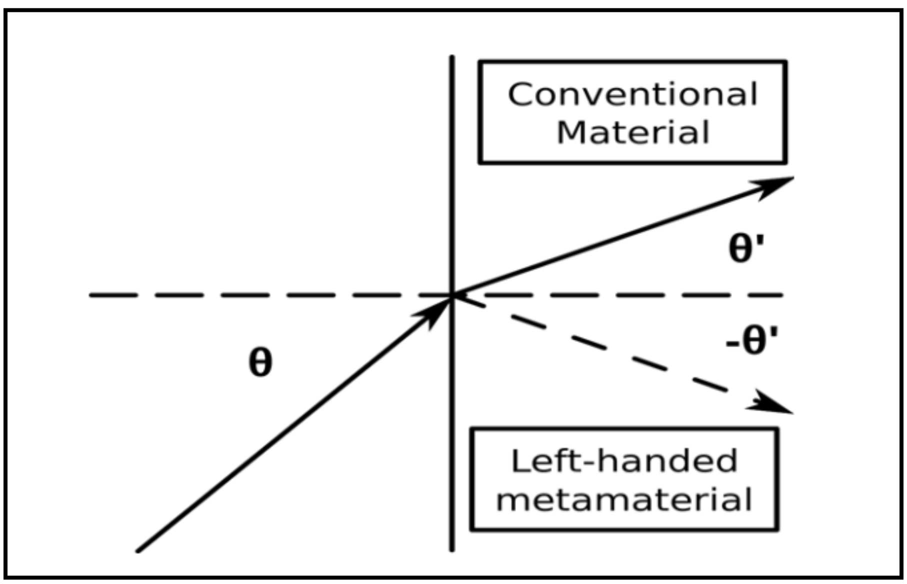

Fig 3.1: Demonstration of ray diagram of metamaterial

According to the illustration, when light strikes the medium's interface, conventional materials will cause the light to be refracted in a positive direction with respect to the normal, while NRI materials will cause the light to be reflected in a negative direction. The 'optical density' of a substance is often determined by its refractive index, which is described as

$$\mathbf{n = c\ v} \qquad (3.2\ 1)$$

Where, c stands for the vacuum speed of light.

In a medium, v gives velocity of an electromagnetic plane wave.

Maxwell relation, derived from the Maxwell's equations, determines the refractive index

$$\boldsymbol{n}^{\mathbf{2}} \mathbf{= \varepsilon\mu} \qquad (3.2\ 2)$$

ε = relative dielectric permittivity and μ = the relative magnetic permeability of the medium.

$$\boldsymbol{n} = \sqrt{\boldsymbol{\mu_r \epsilon_r}} \qquad (3.2\ 3)$$

Now, negative refraction is possible when ($\boldsymbol{\mu_r}$ and $\boldsymbol{\epsilon_r}$) are both negative**.**

$$\sqrt{(-\boldsymbol{\mu r})(-\boldsymbol{\epsilon r})} = \sqrt{\boldsymbol{e}\ -\boldsymbol{j\pi}} \times \sqrt{\boldsymbol{e}\ -\boldsymbol{j\pi}} \times (\sqrt{\boldsymbol{\mu r \epsilon r}})$$

$$= (\boldsymbol{e}\ -\boldsymbol{j\pi}/\mathbf{2}) \times (\boldsymbol{e}\ -\boldsymbol{j\pi}/\mathbf{2}) \times (\sqrt{\boldsymbol{\mu r \epsilon r}})$$

$$= \boldsymbol{e}\ -\boldsymbol{j\pi} \times (\sqrt{\boldsymbol{\mu r \epsilon r}})$$

$$= -\mathbf{1} \times (\sqrt{\boldsymbol{\mu r \epsilon r}})$$

Since all natural materials have negative permittivity, the only challenge was obtaining negative permeability.

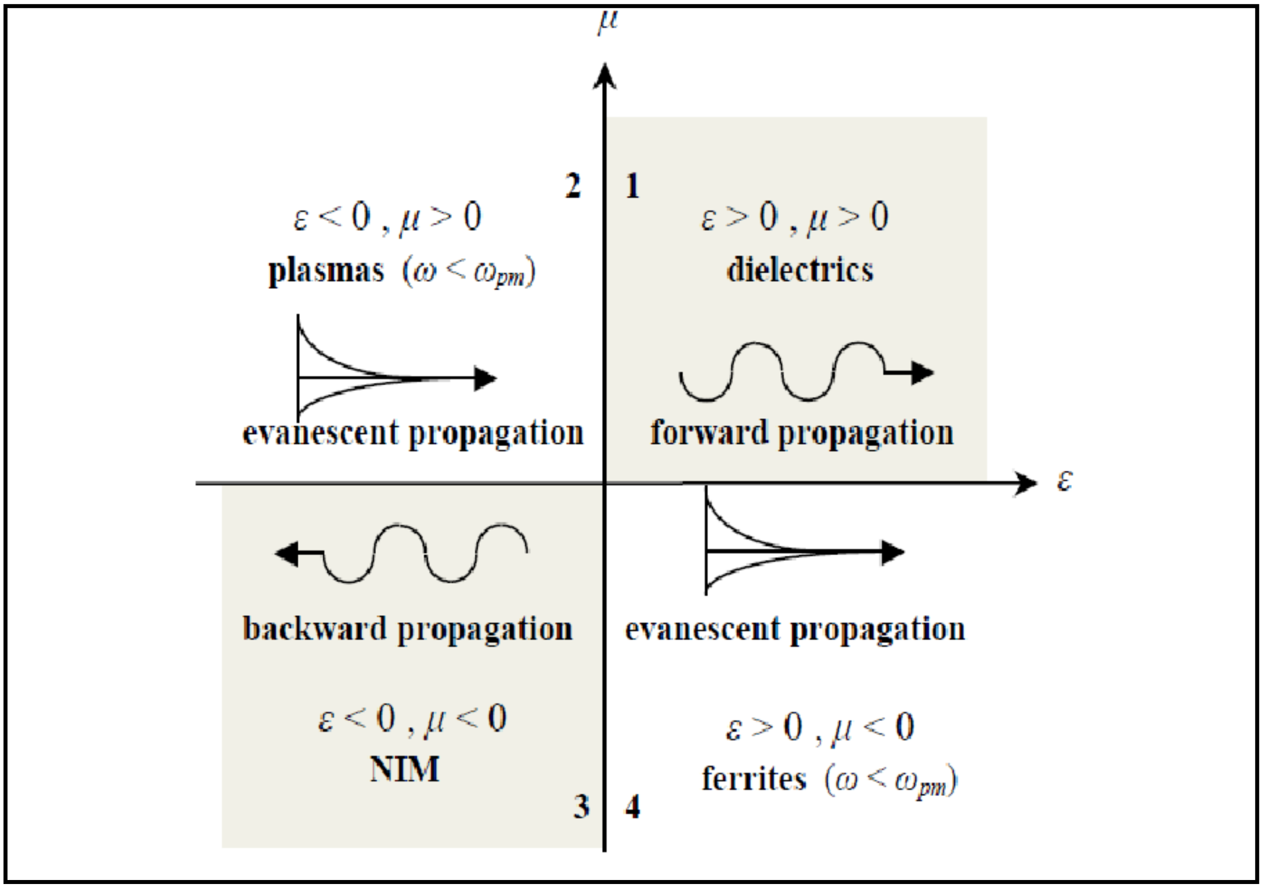

Fig 3.2: Classification of the material based on propagation.

3.3 Phase Velocity, Group Velocity

In relatively narrow-band pulses, the group velocity, denoted by the formula $v_g = \nabla_k \dot{\omega}(k)$, is typically along the Poynting vector's direction and ought to be perpendicular to the phase velocity. The idea of a group velocity, however, might not work for broad-band pulses that are easily distorted due to dispersion. Phase velocity and the pointing vector may both point in the same direction in an anisotropic material. We shouldn't be shocked by this conclusion as a result. The group velocity and negative refraction effect in an NRM have generated some controversial discussion. Refraction at the boundary between the positive medium and an NRM is thought to be positive. The group velocity in an isotropic homogeneous material is

$$\boldsymbol{v_g} = \boldsymbol{\nabla_k \omega(k)} = \boldsymbol{p\hat{k}} \ \frac{\boldsymbol{d\omega(k)}}{\boldsymbol{dk}}$$

In anisotropic media, the phase velocity and the Poynting vector can both be employed.

Since there is isotropy, p ±1. This suggests that, in an NRM group velocity can only be either anti-parallel to or parallel to the phase velocity**.**

3.4 S-Parameters

Scattering parameters (S-parameters) are matrices that are used to characterize the transmission and reflection of electromagnetic waves at various ports of devices like filters, antennas, waveguide transitions, and transmission lines**.**

$$\boldsymbol{S} = \begin{bmatrix} \boldsymbol{S_{11}} & \cdots & \boldsymbol{S_{1n}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{S_{n1}} & \cdots & \boldsymbol{S_{nn}} \end{bmatrix}$$

where S_{11} provides the reflection coefficient at port 1 and S_{21} the transmission coefficient from port 1 to port 2. Verticals$|S_{ij}|^2$ are obtained as the time average power reflection/transmission coefficients. To study the impact of MTM on wave propagation, use the scattering parameters. When impedance matching is taken into consideration, the S parameters are reflective coefficients. As a result, examining those variables yields key information about the guide's propagation quality. The best feasible signal transmission within the defined objectives is shown by the lowest possible reflection coefficient. Low reflection indices suggest high transmission rates. The relative permeability and relative permittivity of metamaterials are computed using the transmission coefficient (S_{21}) and reflection coefficient (S_{11}).

The simplified formulas for the calculation are given below

$$\varepsilon_r = \frac{2}{jkd} \frac{1-S_{11}-S_{21}}{1+S_{11}+S_{21}}$$

$$\mu_r = \frac{2}{jkd} \frac{1+S_{11}-S_{21}}{1-S_{11}+S_{21}}$$

where d = Slab Thickness

CHAPTER-4

DESIGN OF METAMATERIAL

In order to get the desired qualities, metamaterial design is crucial. We construct a metamaterial with a dimension much less than its wavelength. This quality is what gives the metamaterial structure its unique characteristics. Through iterative design and investigation of how different properties respond to various design configurations, the suggested metamaterial will be improved.

4.1 Metamaterial Structure

The metamaterial structure we have chosen here is the Archimedean spiral.

The ancient Greek mathematician Archimedes was the first to investigate the Archimedean spiral. It is a particular kind of logarithmic spiral, which implies that as you progress down the curve, the distance between each turn of the spiral grows or shrinks by a constant ratio [8]. Since Archimedes discussed it in his book "On Spirals," the Archimedean spiral bears his name.

The mathematical equation of an Archimedean spiral in polar coordinates is given by:

$$r = a + b\theta$$

Where:

- **r** is distance from the origin (the radius)

- **θ** is angle measured from the positive x-axis

- **a** determines the initial distance from the origin

- b determines the "tightness" or rate of increase of the spiral.

The parameter "a" determines the initial distance from the origin, while "b" controls the "tightness" of the spiral. The spiral will wind outward as rises if b has a positive value. A spiral will inwardly spiral if b is negative.

Note that in this equation, θ is usually measured in radians. If you want to convert the equation to Cartesian coordinates (x, y), you can use the following conversions:

$$x = r * \cos(\theta)$$

$$y = r * \sin(\theta)$$

These equations will give you the Cartesian coordinates (x, y) corresponding to each polar coordinate (r, θ) point on the Archimedean spiral [9].

A "normal spiral" is a spiral shape that is frequently seen in natural things or standard designs, such as the spiraling pattern of a seashell or the coiling of a spring, when the term is used in daily speech. These spirals may display certain traits like varying size, regular turn spacing, or consistent curvature, but they are not frequently characterized or studied using particular mathematical equations or attributes.

A precise mathematical curve that follows a certain equation or set of mathematical principles is referred to as a "mathematical spiral" on the other hand. It is possible to describe and analyze mathematical spirals using well-defined mathematical tools and formulas. They display particular characteristics like a constant rate of expansion, a logarithmic or exponential relationship between the angle and the distance from the origin, or self-similarity.

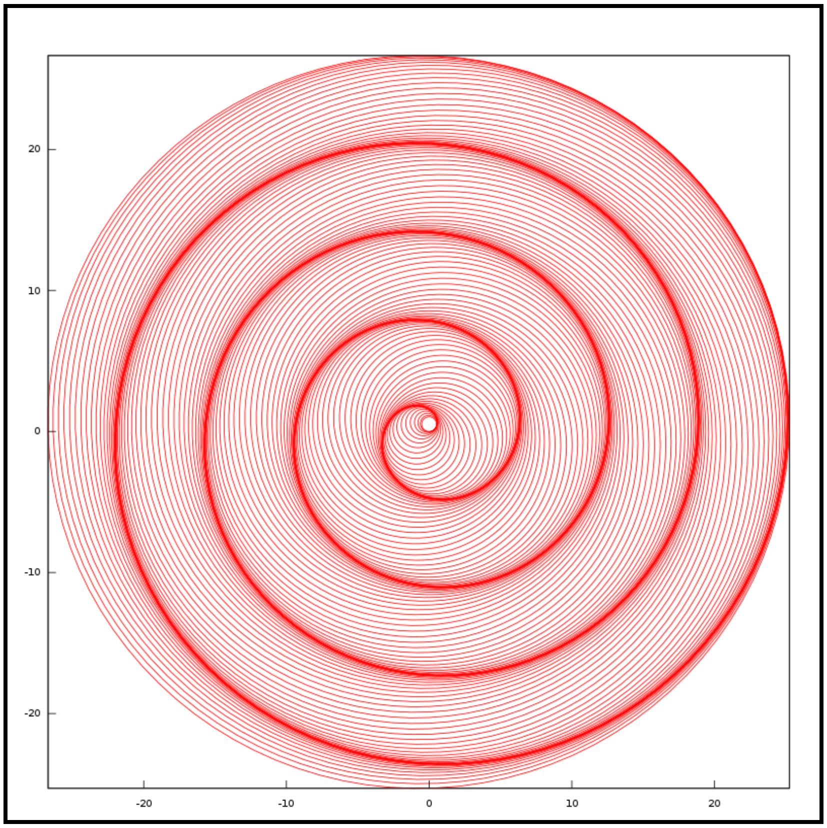

Fig 4.1: Figure of Archimedean spiral

4.2 Two-Arm Archimedean Spiral:

The metamaterial unit structure is based on this structural design is shown in figure :

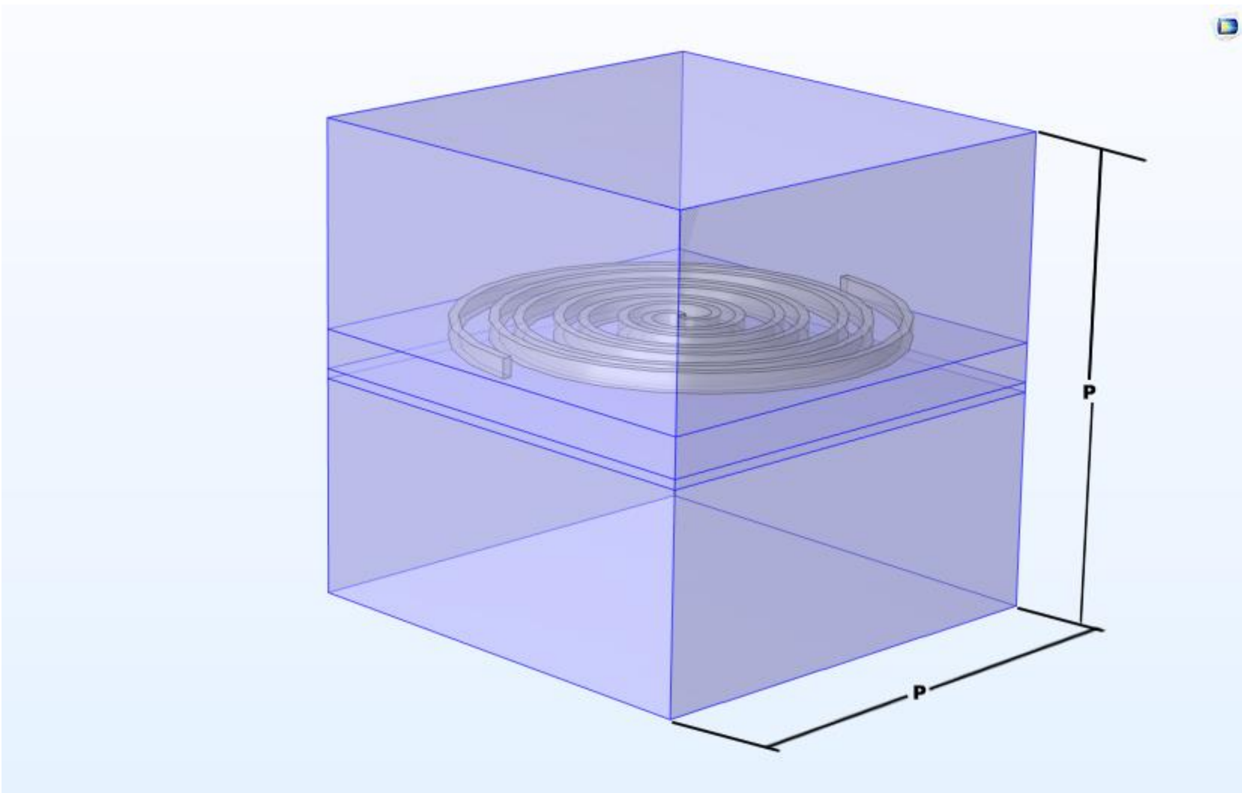

Fig 4.2: Structure of proposed Metamaterial

The unit structure is normally three layers thick, with the upper layer being a two-arm Archimedean spiral, the middle dielectric layer being a FR4 dielectric board, and the bottom layer being a metallic plate. The top and bottom layers are both constructed of metallic copper and have a conductivity (σ) of 5.80*107 S/m, the conductivity of the dielectric substrate is ε =4.3, and the loss tangent t_d =0.025**.**

The specific parameter of the structural unit is:

r = 0.1 mm

Dimension of unit cell **P** = 4.2 mm.

Thickness of FR-4 dielectric board is $\mathbf{t_1}$ = 0.4mm.

Thickness of spiral is $\mathbf{t_s}$ = 0.2mm.

Thickness of metallic Plate $\mathbf{t_2}$ **=** 0.1mm

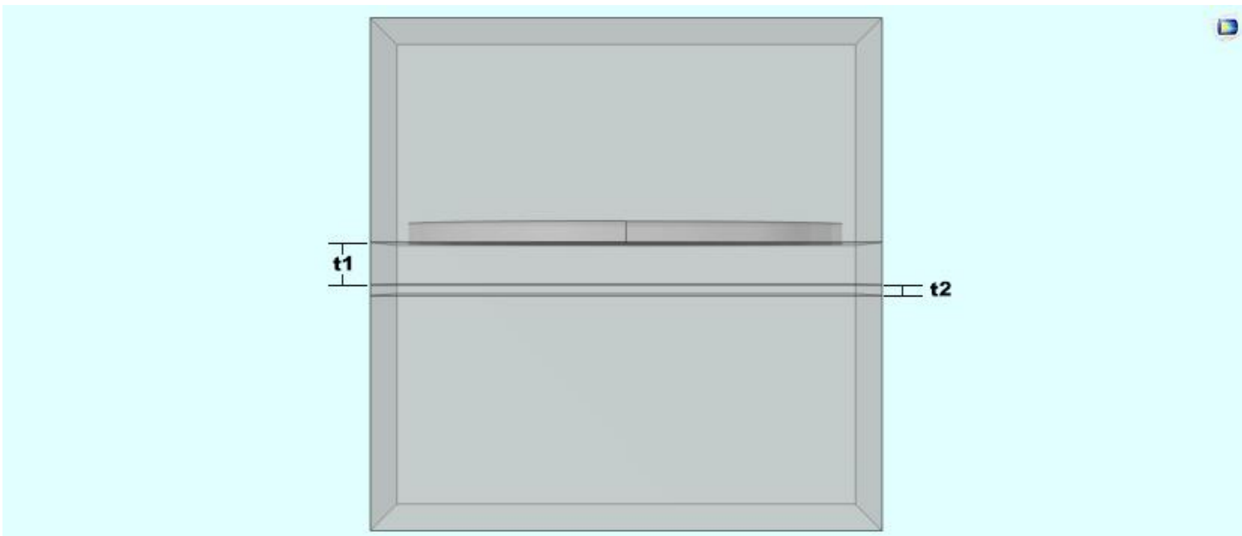

Fig 4.3: y-z plane of proposed metamaterial

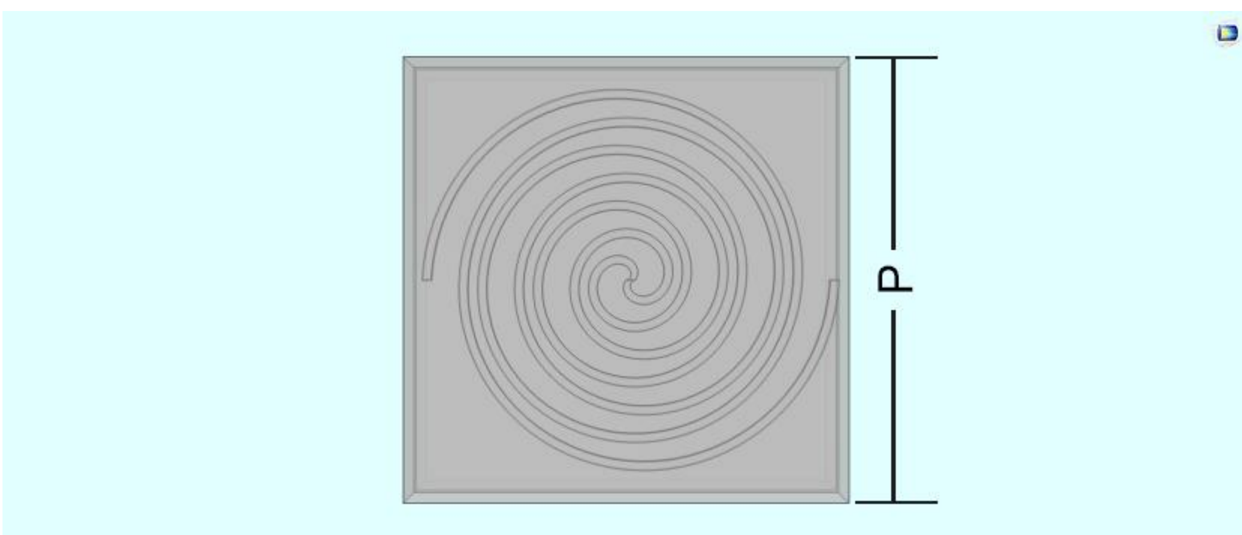

Fig 4.4: x-y plane of the proposed metamaterial

Chapter 5

RESULTS AND DISCUSSION

The results of the design and analysis of an Archimedean spiral absorber for high-frequency microwave applications are presented in this section. Our study's goal was to examine the absorber's performance in terms of its S-parameters, permittivity, and permeability**.**

S-parameter- S-parameters, also known as scattering parameters or transmission parameters, are a collection of measures used to characterize the behavior of linear electrical networks in microwave and radio frequency (RF) engineering. Further, S-parameters are represented as a matrix, generally known as an S-matrix, that relates the amplitudes and phases of input and output signals at various network ports or terminals. Each S-matrix element specifies the complex ratio of one port's voltage or current to another port's voltage or current while keeping the other ports terminated in their characteristic impedance**.**

Permittivity -A material's permittivity is a fundamental attribute that specifies how it responds to an applied electric field. It describes a substance's ability to store electrical energy in presence of an electric field. In layman's words, permittivity is the ease with which electric fields can enter or propagate through a substance. Further, permittivity is commonly symbolized by the symbol Ɛ(epsilon) and is measured in farads per meter (F/m). It is the capacitance per unit length between two conductors separated by a dielectric substance. The greater a material's permittivity, the greater its ability to store electrical energy.

Permeability - A material's permeability is a fundamental attribute that describes its response to an applied magnetic field. It describes a substance's ability to sustain or enable the flow of magnetic flux. In layman's words, permeability is the ease with which magnetic fields can permeate or propagate through a substance. To elaborate, permeability is commonly indicated by the symbol (mu) and measured in Henry per meter (H/m) or newtons per ampere squared (N/A^2). It expresses the magnetic flux density per magnetic field strength unit. The greater a material's permeability, the better its ability to support magnetic fields.

5.1 Estimation of electromagnetic parameters:

Scattering parameter is evaluated in the RF module Finite element approach using COMSOL Multiphysics simulation software and is determined by their characteristic impedance. The electromagnetic plane wave propagates along z-axis, and a Perfect Magnetic Conductor and Perfect Electric Conductor boundary conditions is applied along the y and x-axes, with electric field polarized along the y-axis. The effective medium properties of the proposed structure, namely permittivity (Ɛ), permeability (μ), are calculated using the Nicolson-Ross-Weir technique.

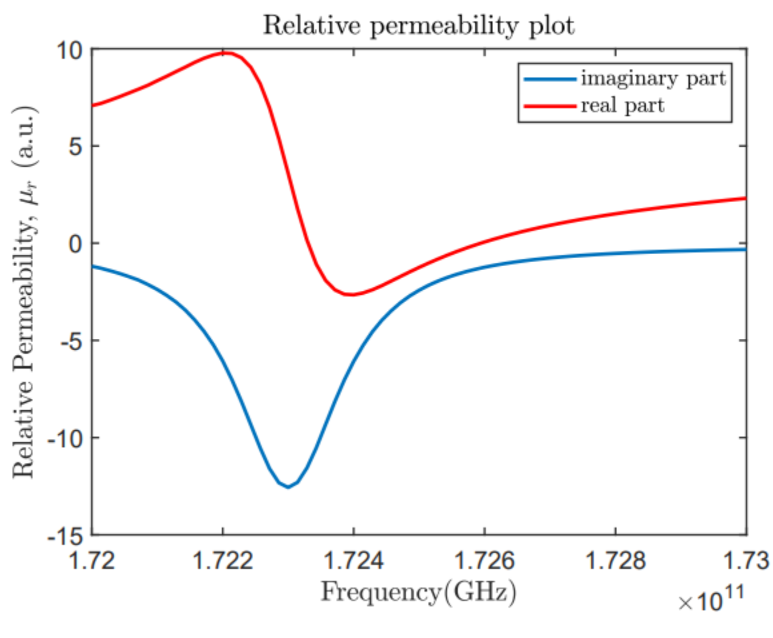

Fig 5.1: Relative Permeability(μ_r) vs Frequency (GHz)

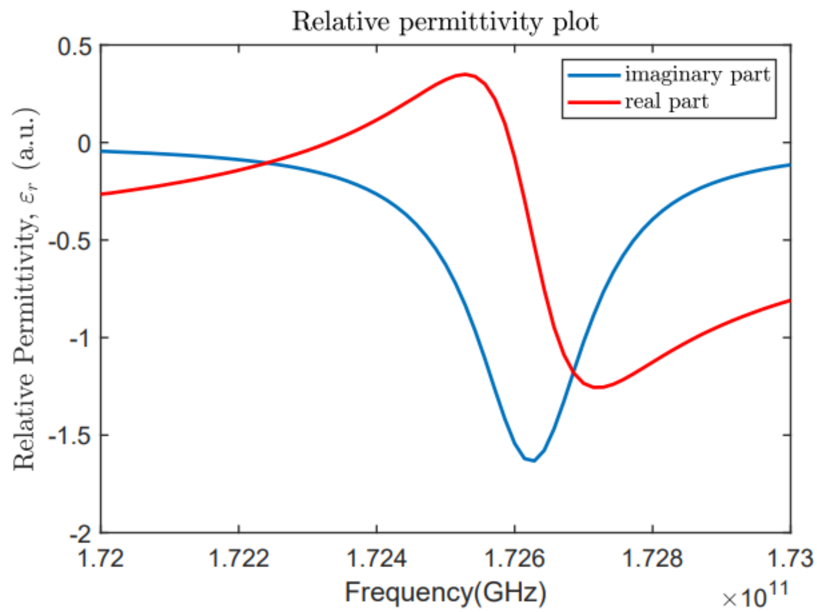

Fig 5.2: Relative Permittivity ($\mathcal{E}_r$) vs Frequency (GHz)

The plot of permittivity (ε), permeability (μ) of the proposed metamaterial is displayed in Fig 5.2. the peak corresponding to frequencies 172.5 GHz, 172.7GHz shows negative permittivity with amplitude 0.4, -1.25 respectively and for permeability there is slight drop on frequency for 172.23GHz as shown in Fig5.1 with amplitude -2dB.

In this proposed Metamaterial design is simulated by using a COMSOL software in frequency domain solver. for this simulation boundary condition are given follows: the frequency is along X-axis and y- direction is S-parameter(dB). we have simulated our structure at different height of spiral with respect of substrate thickness.

The suggested metamaterial unit cell's transmission coefficient (S_{21}) and reflection coefficient (S_{11}) are shown below

1. Estimation of S -parameter and the efficiency of absorption at spiral thickness of 0.20 mm:

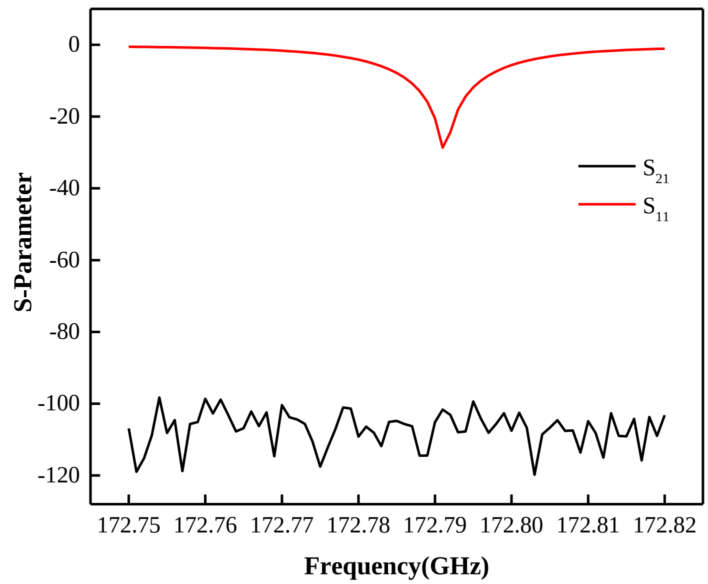

Fig 5.3: Scattering parameter (S_{11} & S_{21}) vs Frequency (GHz) at a spiral thickness of 0.20mm

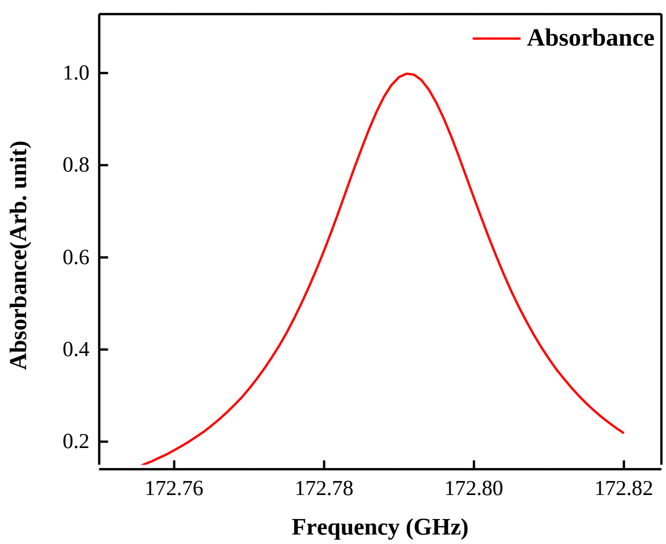

Fig 5.4: Absorbance vs Frequency (GHz) at a spiral thickness of 0.20mm

At the thickness (0.20mm) of the spiral the reflection coefficient(s_{11}) shows a dip at frequency at 172.791 GHz with the amplitude of -28.64 dB correspondingly There is a dip in transmission coefficient (s_{21}) at frequency 172.791 with the amplitude of -101.62 dB. After the simulation and optimization at width 0.19mm we found the absorption coefficient near 99.96%

2. Estimation of S -parameter and the efficiency of absorption at spiral thickness of 0.19 mm:

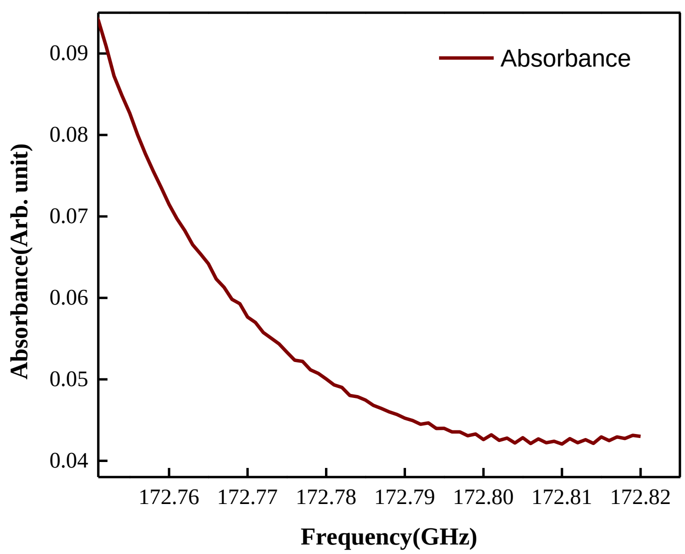

Fig 5.5: Absorbance vs Frequency (GHz) at a spiral thickness of 0.19mm

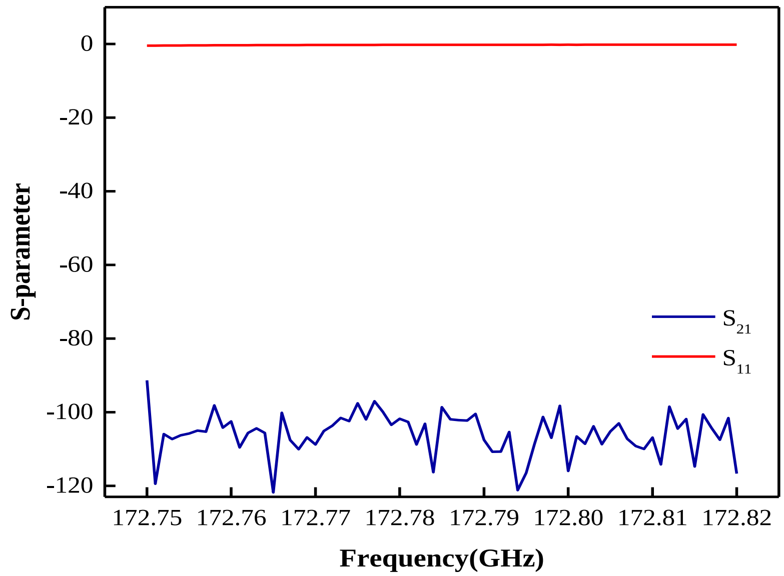

Fig 5.6: Scattering parameter (S_{11} & S_{21}) vs Frequency (GHz) at a spiral thickness of 0.19mm

At the thickness (0.19mm) of the spiral the transmission coefficient(s_{21}) shows a dip at frequency at 172.763 with the amplitude of -104.38 Db correspondingly There is a dip in reflection coefficient (s_{11}) at frequency 172.763 with the amplitude -0.298. . After the simulation and optimization at width 0.19mm we found the absorption coefficient near 10%.

3. Estimation of S -parameter and the efficiency of absorption at spiral thickness of 0.21mm:

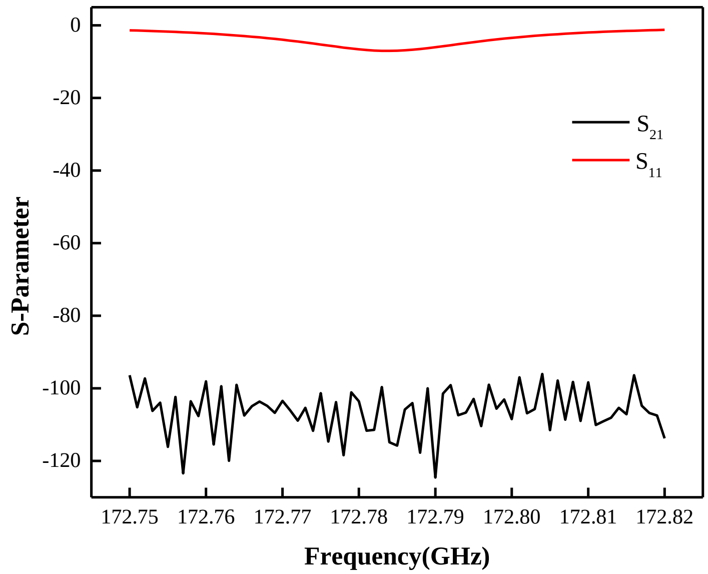

Fig 5.7: Scattering parameter (S_{11} & S_{21}) vs Frequency (GHz) at a spiral thickness of 0.21mm.

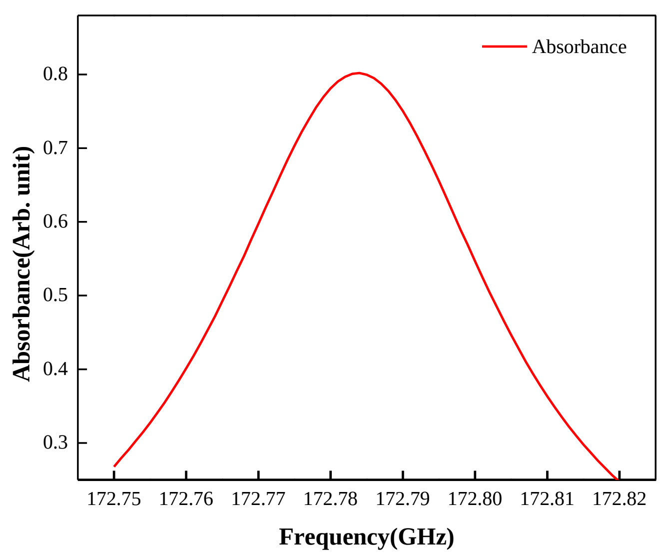

Fig 5.8: Absorbance vs Frequency (GHz) at a spiral thickness of 0.21mm

At the thickness (0.21mm) of the spiral the transmission coefficient(s_{21})t shows a dip at frequency at 172.783 with the amplitude of -99.64 correspondingly There is a dip in reflection coefficient (s_{11}) at frequency 172.784 with the amplitude -7.030 dB . After the simulation and optimization at width 0.21 mm. we found the absorption coefficient is 80 %.

So from different variations, discussed in the results, we can see that the efficiency is greatest at the spiral thickness of 0.20 mm with an absorption efficiency of 99.96%.

Chapter 6

Conclusion

We have examined the effectiveness of a two-arm Archimedean spiral as an absorber for high-frequency microwave applications in the range of 172-173GHz. In addition, the scattering parameter is analyzed. For transmission coefficient(S_{21}), the structure resonates a resonance frequency i.e., 172.791 GHz, the structure exhibits negative permittivity. The two-arm Archimedean spiral structure's distinctive features are responsible for the achieved absorption efficiency. Due to its geometry, incident electromagnetic energy may be coupled and dissipated effectively, which significantly reduces reflections and improves absorption. This absorber design has the potential to reduce the negative impacts of electromagnetic interference, enhance overall performance, and increase the dependability of electronic devices used in high-frequency microwave range.

Figure citation

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2. Fig 2.1: https://www.nissan-global.com/EN/INNOVATION/TECHNOLOGY/ARCHIVE/META_MATERIAL/ASSETS/IMG/meta_material_01_en.jpg
3. Fig 2.2: https://en.wikipedia.org/wiki/File:Z_Antennas_at_UHF_Frequencies.jpg
4. Fig 2.3: https://scx1.b-cdn.net/csz/news/800a/2016/thermalmetam.jpg
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CONFERENCE RECORD

CERTIFICATE OF PARTICIPATION

Azadi Ka Amrit Mahotsav

G20

Department of Physics

Netaji Subhas University of Technology

Sec-3, Dwarka, New Delhi-110078, India

Certificate of Presentation

This certificate is proudly awarded to Prof./Dr./Mr./Ms. Avaneesh Kumar Mishra

from DTU , New Delhi

Paper Title: Design and Analysis of - - - - - - - - - - - - - - applications

For your excellent oral/ poster presentation at the conference and your significant contribution to the success of **International Conference on Advanced Materials for Emerging Technologies (ICAMET- 2023)**, held during **May 4-6, 2023**, at Netaji Subhas University of Technology, New Delhi - 110078, India.

Department of Physics ICAMET May 4-6, 2023 NSUT, New Delhi

Dr. Anurag Gaur
Convener

Prof. Ranjana Jha
Conference Chair

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The Department of Physics, Netaji Subhas University of Technology (formerly Netaji Subhas Institute of Technology) Delhi is organizing an International Conference on Advanced Materials for Emerging Technologies (ICAMET-2023) during May 04-06, 2023 in hybrid mode. The objective of this conference is to provide a common platform for all the researchers, academic personnels, scientists and research students from India and abroad to discuss and share their ideas, and research achievements related to advance materials and their applications for emerging technologies. The themes of the conference have been selected to accommodate a wide range of interests to facilitate interdisciplinary interactions among the participants.

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Registration closes	: 25 April 2023

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The Department of Physics of Netaji Subhas University of Technology Delhi was established in the year 1983 under the School of Applied Sciences. It was created as a separate department in December 2013. The department primarily caters to the teaching requirement of various courses in Physics which form essential component of all undergraduate programmes in the first and second semester at the University. The department also offers M.Sc. Physics course of two years at PG level in addition to Ph.D. Programme.

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An exhibition will be organized during the conference. It will be aimed to prove an opportunity to the manufacturers/dealers of various instruments and its accessories to display their products for the participants of the conference. The exhibits may include technical literature books and equipment. Further, there will also an opportunity to include the advertisement in the souvenir/abstract book.

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