BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

Fan Grill Shaped Circular Split-ring Loaded Metamaterial Absorber For X,K & Ku Band Applications

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DEDICATION

My esteemed teachers and my cherished parents are the recipients of my thesis work, which is devoted to their prayers and encouragement in helping me to accomplish my goal.

CERTIFICATION OF APPROVAL

The thesis “Fan grill shaped circular split-ring loaded metamaterial absorber for X,K and Ku band applications” sumitted by **Kazi Md Maharaz Hossain** to the Department of Electronic and Telecommunication Engineering (ETE) of International Islamic University Chittagong (IIUC) with ID No. **T191059** has been accepted as satisfactory to partially fulfill the bachelor’s degree criteria in Electronic and Telecommunication Emgineering and approved in terms of style and coherence.

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CANDIDATES DECLARATION

I now declare that all of the research included in the above thesis is original to me, with the exception of summaries and quotes that have been properly cited.

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T191059

ACKNOWLEDGMENT

In the name of Allah, the Almighty and Supreme being, the most Gracious and Merciful, All gratitude is due to Allah (SWT) peace and blessings, grace and guidance throughout our lives. May Allah (SWT) peace and blessings be upon our Prophet Muhammad (SAAS), who is our constant source of inspiration. First and foremost, I would like to thank Allah (SWT) for providing me with the capacity and opportunity to complete my study. Second, I would like to express my heartfelt appreciation to my thesis supervisor, Dr. Saif Hannan, for his excellence, essential direction, and encouragement to see my project through to completion. I am also grateful to my convener, Engr. Mohammed Jashim Uddin, for proper guidelines, as well as the Chairman, Emgr. Syed Zahidur Rashid, Engr. Abdul Gafur, Md Mostafa Amir faisal, Md. Ibrahim, Mohammed Woli Ullah, and other respective teachers for their ongoing support and inspiration throughout my journey. Their technical knowledge and perspective aided me in shaping this thesis. And I thank my parents for their continued support in my life. My heartfelt gratitude goes to my close friends, family, and well-wishers for their direct or indirect contributions to the completion of my thesis work.

ABSTRACT

This thesis presents a Fan grill shaped circular split-ring loaded metamaterial absorber for X,K & Ku band applications. The finding demonstrates that regardless of the substrate or polarization angle, the TEM mode absorption rate is constant. With maximum absorptions of 99%, 98%, 99%, 92%, and 99%, respectively, the study shows five resonance gains in the X, K and Ku bands with single negative (SNG) MM characteristics at frequencies of 8.903094, 14.102, 14.606, 20.996, and 21.68 GHz. Due to its superior absorption qualities and clear construction compared with recent work on MM, this absorber has a special function in satellite communication, terrestrial microwave communication and radar communication, comparable works using FR4 substrate.

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LIST OF ABBREVIATIONS

MM	Metamaterial
MMA	Metamaterial Absorber
PMA	Perfect Metamaterial Absorber
mm	Millimeter
SNG	Single Negative
DNG	Double Negative
TE	Transverse Electric
Iot	Internet Of Things
Gbps	Gigabits per second
ENG	Epsilon Negative
ZIM	Zero Index Metamaterial

CHAPTER 1

INTRODUCTION

1.1 Electromagnetic Metamaterials

Metamaterial refers to any material that has been developed to possess a characteristic that is uncommon in naturally existing materials. They are constructed from composite materials, such metals, that are assembled from several elements. Metamaterials that are properly engineered have the ability to modify electromagnetic energy or sound waves in ways that are not seen in bulk materials. Optical filters, medical devices, remote aerospace applications, intelligent solar energy administrators, laser beams, crowd control, radomes, high-gain antenna lenses, improved ultrasonic sensors, and even seismic shielding for buildings are just a few of the numerous potential applications for metamaterials. Metamaterials could be used to create super-lenses.

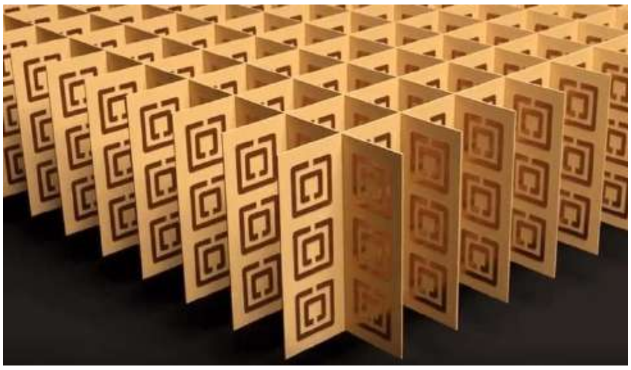


Figure 1.1 Metamaterial [1]

Numerous fields, including the field of optics, the telecommunications, detecting, imaging and antenna design have found use for metamaterials. They can be used to make cloaking devices,waveguides, tiny antennas, effective absorbers, high-resolution lenses, and other things. The distinct characteristics of metamaterials persist in propelling scientific inquiry and advancement within the domain of electromagnetics.

1.2 Metamaterial absorber

A particular kind of metamaterial called a metamaterial absorber is designed to effectively absorb electromagnetic radiation within particular frequency ranges. An advancement in materials science is metamaterials.

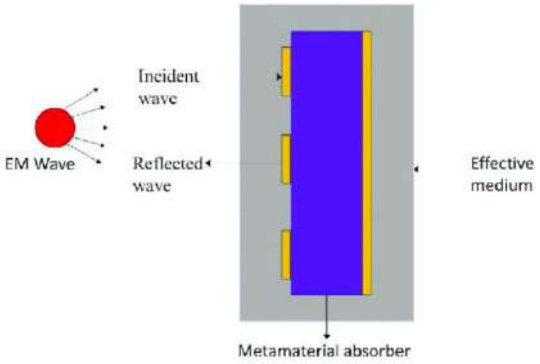


Figure 1.2 Metamaterial Absorber [2]

The Maxwell equations may be used to characterize metamaterial (DaviBiviano 2010). The description of Metamaterial that follows heavily relies on transformations of Maxwell equations:

Time domain Maxwell equation:

$$\nabla \times \vec{E} = -j\omega\mu\overrightarrow{H};\ \nabla.\vec{D} = \rho \text{ --} (1.1)$$

$$\nabla \times \vec{H} = \vec{j} + j\omega\varepsilon\overrightarrow{E}\ \nabla.\vec{B} = 0 \text{ --} (1.2)$$

These equations can simplified for the planar wave.

$$\vec{k} \times \vec{E} = \omega\mu\vec{H};\ \vec{k} \times \vec{H} = -\omega\varepsilon\vec{E} \text{ --} (1.3)$$

As a result, E, H, and K, For positive ε and μ establish a diagonal scheme that is right-handed. If both ε and μ are negative, equation (3) becomes,

$$\vec{k} \times \vec{E} = -\omega\mu\vec{H}; k \times \vec{H} = \omega\varepsilon\vec{E} \text{ --} (1.4)$$

The example study above displays left-handed materials, their corresponding orientation, and the left-hand triplets $\vec{E}, \vec{H}\ and\ \vec{K}$.

Engineers and scientists find metamaterial (MM) absorbers fascinating because of their many uses in mechanical, optical, acoustic, and electromagnetic engineering. Research has been conducted over the past ten years to create ideal and effective MM absorbers to supply EM wave applications. There have been hundreds of designs for microwave magnetic nanoparticle absorbers to date, some of which are ideal MM absorbers in terms of insensitivity to rotational symmetry and co- and cross-polarization. Furthermore, because of their structural insensitivity to cross-polarization, nearly all absorbers are not ideal.

The most popular resonators for these uses are the standard split-ring resonator (SRR), complementary split-ring resonators (CSRR), as well as coupled and non-coupled SRRs. These resonators are well-liked because of their straightforward structural design and simplicity of explanation. While some of these SRRs, CSRRs, or linked SRRs are polarization converters, the majority of them are co-polar MM absorbers [3].

1.3 A Perfect Metamaterial Absorber

An application that offers a metamaterial structure for absorption with almost unity absorbance is a perfect metamaterial absorber. An application that offers a metamaterial structure for absorption with almost unity absorbance is a perfect metamaterial absorber. Emerging technologies like an electromagnetic cloak and unusual properties like a negative index of refraction have been produced by the application of electromagnetic field metamaterials.

The capacity of metamaterials to provide autonomous, customized electric and electromagnetic reactions to incoming radiation is the foundation for the realization of such features. Moreover, the geometric scalability of electromagnetic metamaterials makes them applicable over a large range of the electromagnetic spectrum. Currently, metamaterials are being shown in all technologically significant spectral ranges, such as near-optical, THz, mm-wave, radio, and microwave. The electromagnetic spectrum materials created by this designer provide a great deal of promise for future applications and provide a good platform for examining new emergent physical phenomena [4].

1.4 Properties of Metamaterial Absorber

The electromagnetic characteristics of metamaterials may be described by a range of parameters. A few crucial variables were:

1.4.1 Electric Field (E-field)

It is a well-known fact that a medium's constitutive parameters-specifically, its magnetic permeability and electrical permittivity-determine how that material or substance behaves when subjected to external electromagnetic fields that change over time. Permittivity and permeability are very complex and frequency-dependent due to the lossy and dispersive nature of many substances. Remarkably, one may produce new electromagnetic characteristics not easily found in nature by controlling the sign of genuine components within a material. The use of metamaterials, also known as subwavelength composite material-engineered structures, has increased recently in a number of optical and engineering applications due to their unique electromagnetic properties, which are not found in nature. These properties include backwards wave propagation, subwavelength concentrating in conjunction with super lenses, and invisible cloaking.

The main objectives of this chapter are to present an overview of the behavior of the electromagnetic field and its relations with metamaterials and to study this behavior in a range of metamaterials by means of a combination of analytical and numerical techniques.

1.4.2 Magnetic Field (M-field)

Magnetic metamaterials are materials where negative permeability can be obtained in certain frequency range. They are typically made up of non-magnetic, resonated components of various shapes. Pendry et al. made the first attempt to determine the effective magnetic permeability of a metamaterial.

Metamaterials actively manipulate the magnetic field to generate tailored electromagnetic responses. Metamaterials can exhibit resonance, confine or localize the energy of the magnetic field, and change or suppress it. These features make it possible to use magnetic field control in optical, sensing, and communications applications. A fundamental idea in electromagnetism is that a magnetic field is the force that various magnetic fields or electric fields in the vicinity of Apply an electromagnetic charge, or else a moving electrical charge, to it. The magnetic field's path at a given point in space is determined by the direction in which current flows or by the magnetic poles' orientation [5].

1.4.3 Surface Current

Surface currents are driven by worldwide wind systems, which run on solar electricity. Warm water along the east coast of the United States is transported to Northern Europe by its Gulf Stream, for instance. These currents transfer heat from the tropics to the polar regions. Surface current is a crucial subject in the investigation of electromagnetic waves in terms of how objects behave when they are present. Surface current has a significant influence on influencing the electromagnetic properties of metamaterials, which consist of reflection, absorption, and transmission.

1.4.4 Transmission Line

Metamaterial absorbers can efficiently absorb electromagnetic radiation with a certain frequency or bandwidth. The metamaterial absorber is therefore expected to transmit a small amount while its absorbed frequency or spectrum As stated differently, it is expected that the electromagnetic radiation entering the metamaterial absorber will be attenuated or eliminated during its absorption frequency, or bandwidth.

However, a metamaterial absorber may still be able to transmit the incident radiation at frequencies outside of its absorption frequency or bandwidth with some effectiveness, depending on the absorber's design. According to this, the transmission line of the metamaterial absorber is not zero and may be regulated by adjusting the absorber's design features [6].

1.4.5 Reflectance

Metamaterial absorbers reduce electromagnetic energy reflection within a certain frequency range in order to maximize absorption. The properties of the substrate, the absorber's breadth, and the dimensions and composition of the unit cells all influence how much absorption a metamaterial absorber can handle. According to theory, increasing absorption can reduce the light emitted by a metamaterial absorber. This can be accomplished by developing a metamaterial absorber with an excellent rate of absorption across the required frequency range. The placement of an absorber is crucial to prevent undesired scattering or reflections of the incoming radiation, which might compromise the functionality of the system.

To build an absorber with minimum reflectance, simulations and real-world observations might be utilized to evaluate the efficiency of a metamaterial absorber across a range of spectral frequencies and incidence orientations. While retaining high absorption efficiency, reflectance may be decreased by adjusting design factors, including substrate properties, absorber thickness, and unit cell size and composition [7]. Reflectance is typically expressed as a percentage or a fraction, representing the proportion of incident light that is reflected by a surface.

1.4.6 Absorption

Metamaterial absorber absorption refers to a metamaterial's ability to absorb electromagnetic radiation effectively through a specific frequency range. Metamaterial absorbers are designed to give higher absorption efficacy within a narrow frequency range by leveraging the special qualities of metamaterials, which are composites with electromagnetic properties not found in normal materials. Some of the design elements that impact the metamaterial absorber's absorbance capabilities include the dimension and substance of the unit cell, the width of the absorber, and the properties of the substrate. By adjusting these parameters, metamaterial absorbers with outstanding absorption efficiency over a wide range of frequencies, or those that are specific in their absorption of specific frequencies, can be produced. It is possible to conduct an empirical test of a metamaterial absorber's absorption effectiveness by using techniques such as transmittance and reflectance assessments that are able to determine the absorber's absorption rate. The absorption coefficient, often given as a numerical value, determines the percentage of incoming electromagnetic radiation that reaches the absorber Applications for metamaterial absorbers include detection, imaging, and energy collection when effective electromagnetic radiation absorption within a certain frequency range is necessary [8].

1.4.7 Permittivity

Metamaterials, which are recognized as subwavelength materials, have lately gained popularity in a variety of optical devices and engineering applications because of their unusual electromagnetic characteristics that are not present in nature. These properties include backwards wave propagation, subwavelength concentrating in conjunction with the super lens, and invisible cloaking.

The vacuum is the lowest value of permittivity that can exist. This is also referred to as the electric constant or permittivity of free space; it has a value of 8.85 10-12 Farad/meter and is represented by the number 0. The resistance to the development of fields of electricity is noticeable even in dielectrics. The proportion of a dielectric's unconditional permittivity to its permittivity, represented by the electric constant, is known as its relative permittivity [9].

$$\text{permittivity}=\frac{\text{Electric displacement}}{\text{Electric field intensity}} \tag{1.5}$$

$$\in_r = \frac{\in}{\in_\circ} \qquad (1.6)$$

where,

ϵ_0 is the electric constant

ϵr is the relative permittivity

ϵ is the absolute permittivity of that material.

1.4.8 Permeability

A material's permeability is its capacity to allow magnetic fields or lines of force to form. It explains the material's ability to become magnetized when a magnetic field is applied. The definition of magnetic permeability is "the extent to which magnetic field lines can enter a substance," to put it simply." or "The ability of a material to conduct magnetic field lines.” The Greek letter μ is used to represent it.

$$\text{Permeability} = \frac{\text{Magnitiuide of magnetic induction (B)}}{\text{Intensity of magnetic field (H)}} \qquad (1.7)$$

$$\mu = \frac{B}{\mathrm{H}} \qquad (1.8)$$

If the magnetic permeability of the material is less than μ_0, it is considered diamagnetic. Likewise, a substance is considered paramagnetic if its magnetic permeability is higher than μ_0. [10].

1.4.9 Refractive Index

The ratio of light's velocity in a vacuum to its velocity in a particular medium is known as the refractive index. The same concept is also known by the terms refractive index and index of refraction. The index of refraction and the refractive index are two distinct names for the same idea. The optical density of the medium has an effect on the speed of electromagnetic waves. An optical density is the capacity of a material's components to reflect absorbed electromagnetic radiation. When a substance's optical density rises, light travels slower than before. One such measure of a medium's optical density is its refractive index. The refractive index is a fundamental optical property of a material that describes how light propagates through that material. It is defined as the ratio of the speed of light in a vacuum (c) to the speed of light in the material (v)

There are no dimensions to the refractive index. It is a diagram that illustrates how quickly light waves go through different materials and through vacuums [11].

Light velocity in a vacuum divided by light velocity in a medium is called the refractive index, and it is represented by the sign n. The following is the formula for the refractive index:

$$n = \frac{c}{v} \tag{1.9}$$

Where,

n is the refractive index

c is the velocity of light in a vacuum (3×10^8 m/s)

v is the velocity of light in a substance.

1.4.10 Specific Absorption Rate

The specific absorption rate, or SAR, is a measure of how quickly the body absorbs energy in reaction to electromagnetic radiation, like that from cell phones or Wi-Fi equipment. As a measure of radioactivity, SAR counts the amount of radiofrequency, or RF, energy absorption per unit mass of tissues. It is generally represented as watts per kilogram (W/kg).

$$SpecificabsorptionRate\ (SAR) = \frac{\sigma * E2}{md} \tag{1.11}$$

Where,

σ = Conductivity of Material,

E = Electric Field (RMS),

md = Mass Density.

The SAR value is used to evaluate RF-emitting equipment safety and establish regulatory limits for electromagnetic field exposure. A higher SAR number causes the body to absorb more energy and increases the risk of organ and cell damage [12].

1.5 Satellite Frequency Band

Since satellite technology is developing so quickly, its applications are always growing. Besides wireless communications, satellites are used in many other industries, such as astrology, broadcasting, weather forecasting, and mapping.

1.5.1 L-band (1–2 GHz)

The frequencies in this band range from 1 GHz to 2 GHz. The global positioning system (GPS), mobile satellite services, and certain television services are among the many applications for which it is utilized in satellite communications.

1.5.2 S-band (2–4 GHz)

Numerous communications satellites, shipboard radars, and weather radars—including certain NASA satellites that connect with the Space Shuttles and the International Space Station—use the S-band (2–4 GHz) frequency. Inmarsat and Solaris operating system mobile were each given two distinct 2x15 MHz S-band chunks by the European Commission.

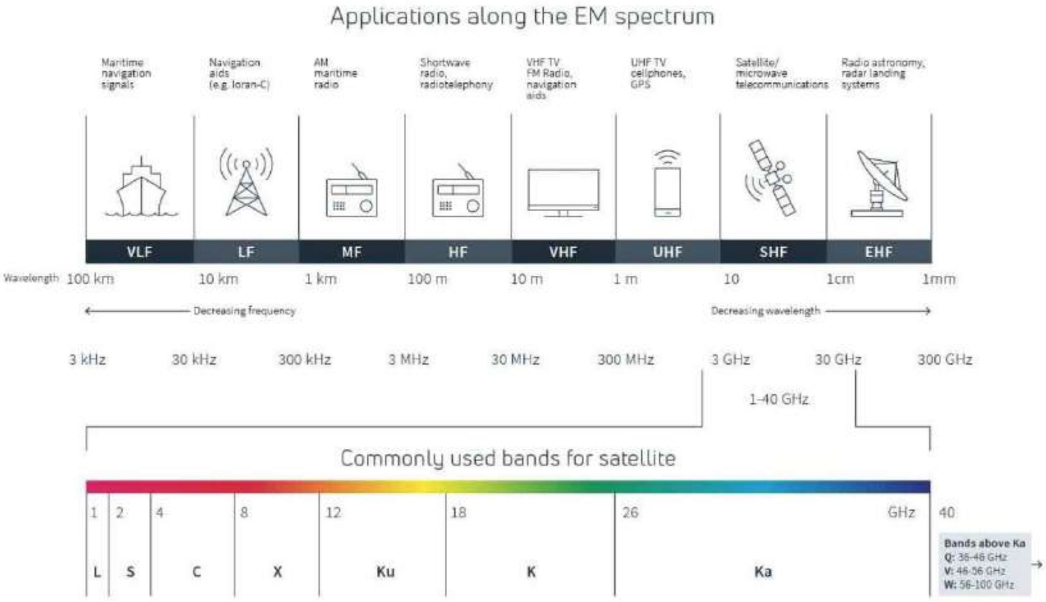


Figure 1.3 Satellite Frequency [13]

1.5.3 C-band (4–8 GHz)

It is primarily utilized in satellite communications, specifically for unprocessed satellite feeds or long-term satellite television networks. In 1962, the first live TV broadcast was sent over the Atlantic aboard the Telstar satellites, which were equipped with a transponder operating at this frequency. Since rain has less of an impact on it across the Ku band, it is popular and commonly utilized in tropical regions.

1.5.4 X-band (8–12 GHz)

The term "X-band" describes a frequency range that is frequently employed in many different contexts, such as wireless networks, radar systems, and satellite communications. The X-band is mostly defined by its frequency range of 8 to 12 gigahertz (GHz), or wavelengths between 2.5 and 3.75 centimeters.

1.5.5 Ku-band (12–18 GHz)

To use satellites for sending and receiving messages. Astra and other broadcast satellite services use the 10.7 GHz–12.75 GHz Ku-band download frequency range in Europe. 26–40 GHz is the Ku-band. military aircraft equipped with short-range, high-resolution targeting radars and communications satellites using the 27.5 GHz or 31 GHz forwarding bands [11].

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Metamaterials (MM) are synthetic materials with special qualities derived from their geometric structure. In addition, they exhibit a few unusual characteristics, including left-handed behavior, reversal of Snell's law, negative refractive index, and reverse Doppler effect. Perfectly lensing, perfect absorption, invisibility cloaking, and sensing are just a few of the many uses for MMs.

The concepts of meta-materials (MM) and MMA are reviewed in this chapter, covering the essentials such as definition, standards, benefits, and uses. This chapter also covers the basic parameters that are always required to be taken into account when designing MMAs, such as the absorption performance, the refractive index, the frequency of the unit's cell, reflecting and transmission coefficients, and negative permittivity or permeability.

2.2 Classification of Metamaterials

Two mathematical groups can be used to explain metamaterials. DNG and SNG structures make up the first group. Alternatively referred to as photon crystals as well as photonic band gaps, materials and PBG structures make up the second group.

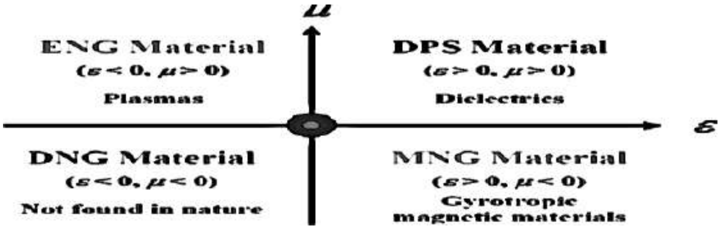


Figure 2.1 The general classification of physical materials depending on the values of permittivity and permeability [14]

Materials classified as "double positive" (DPS) comprise the first group. As the materials with ε and μ values larger than zero are found in both DNG and SNG, dielectrics make up the bulk of this group. In the second group, permeability is greater than zero and permittivity is less than zero. For this reason, they are referred to as Epsilon-negative (ENG) materials. The permeability and permittivity of the third category of materials are both less than zero. Mu-negative (MNG), or gyro tropical magnetic, materials can be described by these features. The fourth group consists only of synthetic double-negative (DNG) materials. This type of material exhibits both negative permeability and negative permittivity (below zero).The motion of an electromagnetic wave varies when it penetrates these materials. No substance found in nature possesses both negative permittivity and negative permeability. According to the list above, metamaterials are a unique class of material designed to have both negative permeability and negative permittivity [15–19]. A more inclusive definition of metamaterials is being used, though, since more structures with distinctive qualities and uses are created. Designed to achieve a complicated interaction with electromagnetic waves, it is a man-made macroscopic composite that lacks the naturally occurring material needed to achieve the desired performance [20,21].

2.3 Microwave Metamaterial Structure

Materials created specifically to exhibit distinct electromagnetic properties not found in naturally occurring materials are known as microwave metamaterial structures. Subwavelength components such as split-ring resonances, metal-based cables, and dielectric resonators are arranged in regular groups to create these structures.

In order to affect electromagnetic waves in a manner that regular materials cannot, metamaterials are commonly developed. Some properties that they may possess include perfect absorption, which enables effective energy absorption over a wide frequency range, or an adverse refractive index, which permits exceptional light bending. Applications including microwave frequencies that can make use of metamaterial structures include radar technology, wireless power transfer, cloaking devices, antenna design, and electromagnetic wave manipulation.

2.3.1 Classification Scheme

The two main classes of metamaterials can be distinguished by their approaches toward a mathematical description. The first class includes DNG and SNG structures, whereas the second class includes PBG structures, also referred to as photonic crystals or as photonic bandgap materials. In both DNG and SNG materials, the internal particle linear dimensions are significantly less than the operational wavelength, as previously noted. As a result, these media are typically homogenized and referred to as effective media. In PBG-structures, the distance between each component element is at least half the wavelength.

Consequently, photonic crystals are not homogeneous media. They are typically characterized through Bragg reflection, which is not significant in DNG and SNG structures and is substituted with alternative methods for periodic media.

The categorization method shown in Fig. 2.2 was developed after reading books and publications that emphasize the basic metamaterial concepts for microwave applications [22].

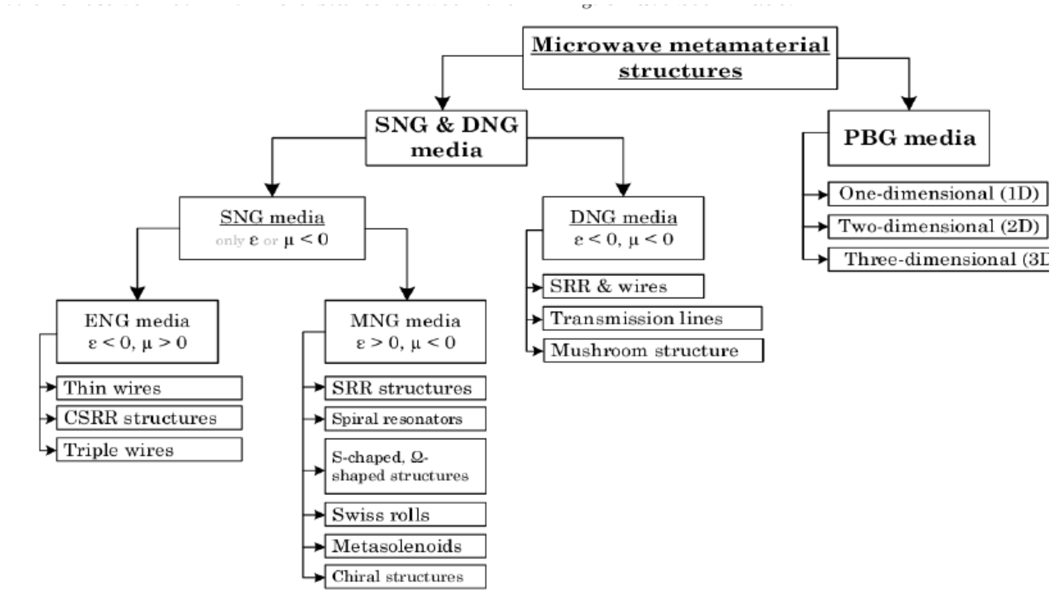


Figure 2.2 Classification of microwave metamaterial constructions [22]

2.4 Epsilon-negative Metamaterials

A class of synthetic materials called epsilon-negative (ENG) metamaterials, or negative permittivity materials, is made to have a negative permittivity (ε) value. Natural materials have a positive permittivity, a property that indicates a material's ability to retain electricity in an electric field.

ENG metamaterials, on the other hand, have been designed to have a negative permittivity, which produces peculiar electrical characteristics [23]. To obtain a negative number of ε, the metamaterial is employed for a metal-based network of small wires. Effective permittivity may be stated as:

$$\varepsilon\ p= 1- \omega\ 2\ p/\omega 2 \tag{2.1}$$

where ω is the electromagnetic wave's propagation frequency and ωp is the plasma's frequency. This formula states that when the effective permittivity value is lower than the plasma frequency, it is negative. A zero index of refraction results from the effective permittivity being zero if it operates at the plasma frequency [24].

The distinct configuration of the constituent elements in ENG metamaterials is the source of their negative permittivity. These materials typically comprise subwavelength elements, like metallic or split-ring resonators, that are specifically designed to engage with electromagnetic waves. This constructed configuration is the cause of the negative permittivity response. Because ENG metamaterials can exhibit anomalous properties like negative refraction, there has been a lot of interest in them. Electromagnetic waves bend in the opposite direction within an ENG metamaterial than they do through a regular material. This property is useful for wave manipulation, imaging, and lensing.

2.5 Mu-negative Metamaterials

Negative permeability materials, or mu-negative (MNG) metamaterials, are synthetic materials created to have a negative permeability value (μ).Double-negative (DNG) metamaterials are produced by combining MNG and epsilon-negative (ENG) metamaterials. These metamaterials are used in antennas for wave manipulation, cloaking devices, and connectivity. The most traditional and often utilized MNG architecture is the split-ring resonator (SRR). SRRs with a round or square shape can both have excellent conductivity. An applied, time-varying magnetic field produces currents that, when applied perpendicularly, produce a secondary magnetic field. The resonant qualities of the structure determine whether it opposes or enhances the incident field, leading to either a beneficial or adverse μ eff. resonance structures in which the inductance is balanced by a capacitor between the two rings [22].

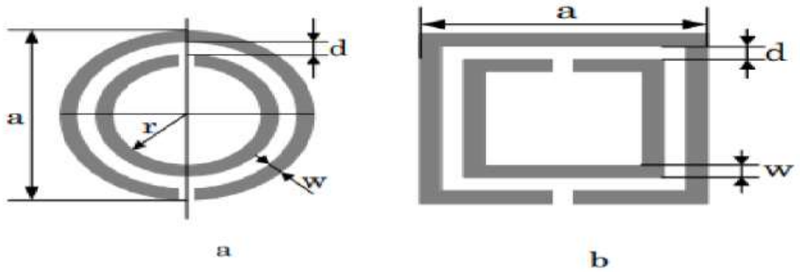


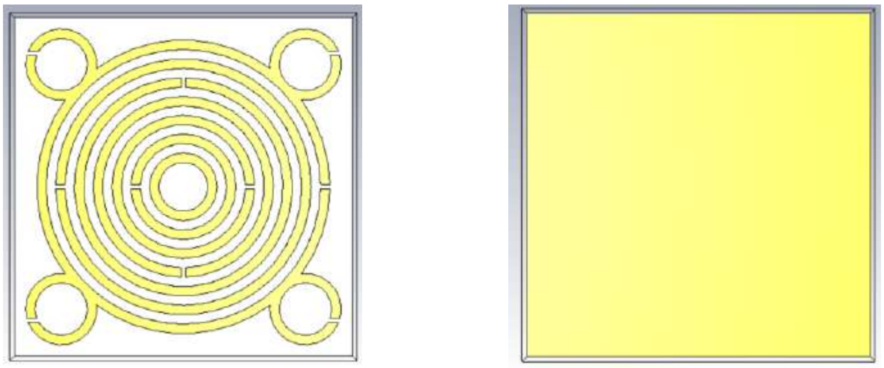
Figure 2.3 The first MNG-material unit cells: a) round, b) square [25]

2.6 Metamaterial Absorber

Synthetic materials called metamaterials have characteristics not present in natural materials that allow them to regulate electromagnetic waves [26]. MMs usually consist of a layer of dielectric that has metal laminations on either one or both of its sides. The different structures of the metal layers include strip lines and capacitive gaps. Radar, microwave, and antenna sensors' dielectric mediums can be affected by negative permittivity or permeability values, as well as refractive index values, when it comes to electromagnetic radiation propagation. The microscopic effects that influence in-effect permeability or permittivity are strongly supported by the designed metal stacking across a dielectric layer, which generates such artificial MM characteristics. Single-negative (SNG) or double-negative (DNG) materials are those that exhibit a single-negative (SNG) or double-negative (DNG) proportion of permittivity and permeability in relation to their dielectric substrate when MM applies EM waves to them [27]. Conversely, artificial structures known as metamaterial absorbers (MMA) exhibit both SNG and DNG properties at resonance frequencies and are capable of efficiently absorbing incoming electromagnetic waves. MMA has the potential to function as a partial absorber or polarization converter, contingent on the symmetry and structure of the metal patch. Although an MMA typically has a metal ground layer, an MM could or could not have one.

2.6.1 Structure of the Proposed Metamaterial Absorber

The majority of the time, the metallic-based MMA's top surface serves as the patch metal lamination, while the bottom surface serves as the ground metal lamination. This dielectric substrate layer can be single or multi-layered. Typically, substrate metal-laminated surfaces are made of melted copper, gold, silver, and so on. Materials that act as dielectrics can be liquid or solid substrates. The figure displays a broad overview of an MMA.MMs usually consist of a layer of dielectric that has metal laminations on either one or both of its sides. The different structures of the metal layers include strip lines and capacitive gaps. Radar, microwave, and antenna sensors' dielectric mediums can be affected by negative permittivity or permeability values, as well as refractive index values, when it comes to electromagnetic radiation propagation. The microscopic effects that influence in-effect permeability or permittivity are strongly supported by the designed metal stacking across a dielectric.



Patch View Ground View

Figure 2.4 Structural view of the proposed metamaterial absorber

Any direction of EM waves is permitted to travel through the MMA, and at its resonance frequencies, the absorber is meant to efficiently absorb the waves.

2.6.2 Features of Metamaterial Absorber

For EM wave absorption, MMA is evaluated using the generic equation.

A = 1 -|5_(11^2)| –|5_(21^2)| (2.3)

The transmission coefficient, like that of incident waves, is the proportion of the transmission waves to the incident wave, while the reflection coefficient is the opposite. The symbols |S11|2 and |S21|2 stand for the transmission and reflection coefficients, respectively. Figures help to understand the concept of MMA.

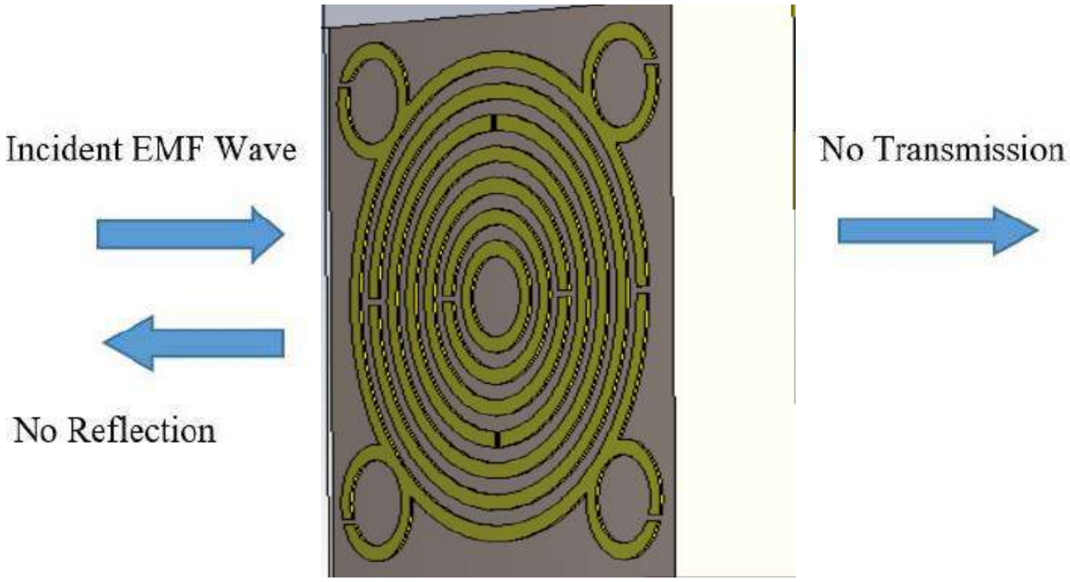


Figure 2.5 Absorption by an MMA

To find the S parameters, two wavelength guide ports are typically used on both MMA surfaces. The following is an explanation of the scattering (S) parameters (s11 and S21).

$$\mathrm{S11} = \frac{\sqrt{\text{power reflected from port1}}}{\sqrt{\text{power reflected from port2}}} \tag{2.4}$$

$$S21 = \frac{\sqrt{\text{power reflected from port2}}}{\sqrt{\text{power reflected from port1}}} \tag{2.5}$$

Liu et al. (2012) state that the S parameters are defined by the electric field. On the port, the computed electrical field, Ec, is the space between the excitation and then the reflecting field. It functions as an MMA in situations where the applied EM waves are not reflected or transmitted by the MM. In addition to absorbing electromagnetic waves, an MMA also exhibits negative permittivity or permeability, which results in a negative refractive index. Because it is uncommon in nature overall, this quality is referred to as a metamaterial characteristic [28].

2.6.3 Single Negative (SNG) Metamaterial Absorber

Single-negative (SNG) metamaterials are those that have a single permeability or permittivity. There are two types of SNG metamaterials: Epsilon-negative (ENG) and Mu-negative (MNG). Epsilon-negative metamaterial is defined as having both positive permeability and negative permittivity. Natural plasmatic materials display negative permittivity at optical frequencies, which is a property of the ionospheric plasma layer. Mu-negative metamaterial is defined as metamaterial that demonstrates both negative permeability and positive permittivity. In the higher frequency range, ferromagnetic materials show negative permeability. Prior to this, a wave-reflecting experiment was conducted using a single slab of MNG along with a slab of ENG material. Zero reflection, transparency, and resonances all contribute to the experiment's outcome. Dispersive SNG metamaterials exhibit variable effective characteristics as a function of frequency. An absorbent that possesses any of these qualities is known as SNG MMA, as was previously mentioned. Epsilon-negative metamaterial is defined as having both positive permeability and negative permittivity.

2.6.4 Near Zero-Index Metamaterial Absorber

Metamaterials classified as zero-index metamaterials (ZIM) have permittivity and permeability that, at a certain frequency, are both simultaneously or independently equal to zero. When a wave enters a medium with a zero refractive index, its wavelength and phase velocity are both nearly infinite. Additionally, while the dipole inside these metamaterials oscillates in synchrony, it offers a quasi-uniform period for electromagnetic waves. As a result, these media show strong directed waves and hardly any transitional period [29]. The far-field pattern of the antenna can be limited by using zero-index metamaterials. A longer planar area might be covered by a highly focused, collimated beam projected by an evenly phased radiation field [30]. By regulating the direction of emission, the ZIM also improved the micro-strip patch antenna's directivity [31].

Further categories of zero-index metamaterial include EnZ and MNZ, or else epsilon near zero as well as mu near zero. The permittivity values of the metamaterials that are epsilon-near-zero, or ENZ, are actually very close to zero. The phrase "metamaterial that is Mu near-zero" (MNZ) refers to metamaterial whose real permeability value is close to zero. Space filtering [32], improving radiation directivity [33], and coupling and compressing electromagnetic energy [34] are a few applications for this kind of metamaterial. Because ENZ metamaterials have intrinsic negative polarizability and rapid wave propagation, they may be used for cloaking and transparency [35].

2.7 Frequency Targeted Metamaterial Absorber

A patterned patch design is typically used in MMA design in order to achieve maximal absorptions at resonant frequencies. Resonance frequencies are frequently specific, nameless frequencies that are not particularly helpful since they are not assigned to practical, application-oriented frequencies that are beneficial in the actual world. Furthermore, the rationale for the foundation cannot be explained by these metamaterials. Neither address resonances nor make any mention of a relationship between design requirements and resonance frequencies.

Therefore, it is rare to come across MMA that focuses on frequency. Table 2.1 provides an overview of some of the frequency-targeted MMAs currently in use.

A frequency-targeted metal-halide photovoltaic cell (MMA) is designed to show resonant at certain frequencies, along with maximal absorptions and metamaterial properties, in order to be employed in real-world applications.

There should be a process and a formula to create and obtain the required outputs in order to obtain such MMAs. When constructing frequency-targeted MMA, one of the most important considerations is the structural parameter.

Frequency-targeted metamaterial absorbers are designed to efficiently absorb electromagnetic radiation that falls into a certain frequency band. In order to do this, the metamaterial structures' composition, size, and form are specifically designed to interact with waves to improve absorption at the target frequency.

2.8 Performance Evaluation of Metamaterial Absorber

Before being suggested for possible real-world use, the MMA should first go through a performance review. MMA has several uses in the world of electromagnetic communication. These MMAs may fulfill the unique EM response requirements of each application at the specified frequencies. An MMA should be examined prior to being proposed for a specific application, such as directivity increase in high-frequency antennas, EM cloaking, microwave detection, radar cross-section reduction, and so on. A few parameters are included in the absorber's performance assessment. An appropriate equivalent circuit technique should be used to describe the absorber's electromagnetic behavior. In order to evaluate it practically and suggest possible applications, the absorber should finally be assembled as both an array and a unit cell.

2.9 Challenge of Metamaterial Design and Future Development

The talks in the earlier parts make it abundantly evident that creating MMAs for random resonance frequencies is simple, but creating MMAs for real-world applications that are frequency-focused is more difficult. The days of building MMA randomly are over; instead, MMA should be suggested for real-world uses. Recent research does not provide any instances of actual applications or IEEE-allocated frequency-oriented MMA.

Furthermore, there aren't many ideal frequency-selective MMAs. There isn't a method or procedure for designing MMA that is application- or frequency-focused.

Fortunately, the MM features are also present in all of the suggested absorbers; however, it is not possible to adjust these qualities to resonance frequencies. Given that MMA designs mostly employ commercially accessible substrate materials, an engineering approach or formula should exist to create MMAs with specific frequency targeting utilizing these substrates. Since MM and MMA have emerged as viable technologies to increase the necessary performance of communication networks, it is therefore imperative that they be developed in this decade. Using multi-layered substrates or adding lumped components to the patch structure are simple ways to achieve broadband absorption. However, because these absorbers lack MM characteristics at the necessary frequencies, they are not practicable for use in real-world applications.

MM characteristics cannot be obtained with such so-called broadband absorbers across their complete working frequency range. MM characteristics like SNG or DNG are only present on a small number of isolated frequencies, neither in the broadband nor narrowband span. Because of these restrictions, the only absorption peaks that are viable for real-world applications are those with sharp MM characteristics. Therefore, using several layers or lumped pieces is discouraged. Additionally, those merged components or multi-layered substrates may cause some mechanical issues.

One may lose part of the aggregated components from an unsmooth patch surface, for instance, due to surface friction or an accidental mishap. Apart from the ungluing caused by heating, problems can also arise from intra-layer dislocation and from the substrate being too thickened in several layers. The only way to overcome these drawbacks is to use MMAs with only one substrate layer and no lumped components in the cell unit patch.

2.10 Review of Previous Work

Reviewing relevant works by other researchers for this thesis will be done in this part. Fan grill shaped circular split-ring loaded metamaterial absorber for X, Ku & K band applications. I revirews some of paper which is relevent with my design. I reviews them below:

1)A Polarization Independent Quasi-TEM Metamaterial Absorber for X and Ku Band Sensing Applications [36].

This work presents the introduction of mirror-reflexed C-shaped dual-band metamaterial absorber (MMA) rings for X and Ku band applications in sensors. The mirror-reflexed C-shape and two squared ring resonators make up the suggested metamaterial, which exhibits two unique bands of absorption across the electromagnetic wave in the electromagnetic spectrum. In particular, the two-band absorber's mechanism shows two resonance frequencies, as the quasi-TEM field distribution was used to study absorption. By adjusting the metallic ring's size in the frequency spectrum, the absorption may be adjusted. The CST microwave studio simulations program, which is based on the finite-integration method (FIT), was used for the design and study of the suggested meta-absorber. There are two distinct absorption peaks around 13.78 GHz and 15.3 GHz, with values of 99.6% and 99.14%, respectively. Measurements and comparisons with computed findings have been made on the absorption results. Potential uses for the suggested dual-band absorber include radar systems and satellite communication sensing methods.

2) A simplified design of broadband metamaterial absorber covering X- and Ku-band [37].

This paper presents the straightforward design of a wide-spectrum metamaterial absorber (MA) covering the X- and Ku-bands. By examining the comparable circuit model, this study extends the process of using COMSOL simulation software to analyze and optimize the structural characteristics of the MA. According to the results of the simulation, the planned MA has strong absorption characteristics at wide incident angles and an absorptivity of over 90 percent at average incidence throughout equally transverse magnetic (TM) as well as transverse electric (TE) division over the entire X- and Ku-band (8 GHz–18 GHz).Additionally, the MA built in this study includes an actual and relative frequency using up to 10 GHz and 76.92%, accordingly, while maintaining a simple design without accounting for the loading of lumped sections or the use of innovative materials, in contrast to earlier research. The finding has potential implications for reducing radar cross-section, boosting stealth, and improving the electromagnetic compatibility of devices.

3)A wrenched-square shaped polarization independent and wide angle stable ultra-thin metamaterial absorber for S-band, X-band and Ku-band applications [38].

This work presents a miniaturized ultra-thin absorber loaded with metamaterial that is independent of quad-band polarization. The suggested absorber's construction is made such that each of the two resonators alone contributes to three absorption bands, while the combination of the aforementioned resonators results in four absorption bands. Four distinct absorption bands are seen in this proposed metamaterial absorber, with peak absorptivity values recorded at 95.75%, 95.93%, 97.69%, and 95.64%, respectively, at 3.2, 5.32, 11.15, and 16.73 GHz. The bandwidths identified as the simulated full width at half maximum (FWHM) are 90 MHz (3.15–3.24 GHz), 220 MHz (5.21–5.43 GHz), 410 MHz (10.94–11.35 GHz), and 700 MHz (16.38–17.08 GHz), in that order. To further reduce the unit cell, its electric dimension is lowered to 0.11 λ0 × 0.11 λ0, which is the same for the free-space wavelengths (λ0) calculated from its lowest absorption frequency. With a thickness of only 0.01 λ0, the intended absorber structure is very thin. This suggested unit cell's metamaterial characteristic has been verified through the discussion of dispersion diagrams, magnetic permeability, and complicated dielectric permittivity. The absorber unit cell structure's fourfold symmetry accounts for its polarization insensitivity. Applications for the suggested ultra-thin absorber include imaging, wireless applications, sensing, electromagnetic interference suppression, and stealth technologies.

4) An Ultrathin, Triple-Band Metamaterial Absorber with Wide-Incident-Angle Stability for Conformal Applications at X and Ku Frequency Band [39].

This work presents the creation of a triple-absorption peak metamaterial absorber (MA) that is ultrathin and flexible. From 8.5, 13.5, and 17 GHz (also known as the X and Ku bands), each of the peak measurements of the recommended absorber has an absorption of 99.9%, 99.5%, and 99.9%, respectively. The recommended construction has a thickness of just 0.4 mm, which corresponds to the wavelengths of the relevant free space absorption frequencies in the various bands of 1/88, 1/55, and 1/44.The symmetric shape of the MA makes it insensitive as well. Furthermore, within a 60° angle of incidence, the suggested structure shows a minimum of 86% absorption (TE incidence). The suggested absorber has as much as 99% absorptivity for TM incidence up to 60°. To examine the mechanisms regulating absorption, the distributions of surface energy and electric field were studied. For the purpose of optimizing absorption, parameter assessments were carried out. Furthermore, a sample that is being tested has 20 x 30 unit cells that are produced across a flexible dielectric, was used to experimentally show the efficiency of the MA in free space. The manufactured MA displays near-perfect absorbance at every peak of absorption across all polarization angles under normal incidence, and the modeling and experimental findings were determined to be in agreement The high-efficiency absorption of the recommended absorber is advantageous across a broad range of incidence angles, making it suitable for electromagnetic shielding and energy harvesting applications.

5) Broadband Metamaterial Microwave Absorber for X-Ku band Using Planar Split Ring-slot Structures [40].

This study describes the design and fabrication of an advanced broadband metamaterial microwave absorber. Five-unit cells of different geometrical dimensions which were designed using CST simulator, achieved at least 80% absorption of microwave at 11 GHz, 12 GHz, 13 GHz, 14 GHz and 15 GHz, respectively. The split ring resonator and microstrip slot structure, which were printed in a repeating pattern on both sides of the FR-4 substrate in 1.58mm and (20×20) cm2 absorber thickness and area, respectively, made up the suggested metamaterial absorber unit cell. In contrast to a traditional linear slot structure, the microstrip slot structure developed in this study has several width sections. The geometrical dimensions of the metamaterial absorber have been studied parametrically and analyzed. The absorption peak shifted by 1 GHz from a lower to a higher frequency as a result of the unit cell's average 7% shrinkage. Using a free-space measurement approach, metamaterial absorbers were experimentally evaluated in the X-Ku band, where their flat surface was normal to the incoming wave (in-plane). The findings of the S-parameters test demonstrated that the metamaterial's absorption characteristics for the normal incidence scenario (in-plane) differed marginally from the modeling results by moving the frequency by 0.3 GHz.

6)Broadband Perfect Metamaterial Absorber on Thin Substratefor X-Band and Ku-Band Applications [41].

An FR-4 Epoxy substrate covered using broad-band Perfect Metamaterial Absorber (PMA) is recommended for X-band and Ku-band applications. The unit cell structure is composed of appropriately oriented rectangular patches that form on top of a metal-backed dielectric substrate with a thickness of 2.7mm (0.16 µL). The normal absorbance bandwidth for the entire X-band and Ku-band of microwave wavelengths is 79% (over 85% absorption).By examining the surface current distribution in the top and bottom planes, the structure's absorption mechanism has been elucidated. The broadband properties of the design support the assertion that it can be used for a wide range of commercial and research applications. These include military and stealth gear, thermal sensors, and electrical cloaking devices.

7) Simple Design of a Wideband and Wide-Angle Insensitive Metamaterial Absorber Using Lumped Resistors for X- and Ku-Bands [42].

We present a metamaterial absorber that is insensitive to polarization and broad angles, and it is built upon a symmetry structure that is connected to surface mount resistors. The suggested construction consists of a constant metal ground plane divided by a FR-4 dielectric substrate and periodic arrays of an upper metal symmetry resonator loaded with four lumped resistors. The suggested absorber's prototype is built and measured, and the results of the simulation and the measurements correspond well. For each transverse magnet and transverse electric polarizations, the proposed absorber shows absorption responses and polarization-insensitive behavior across the 8–18 GHz frequency spectrum, including the whole X- and Ku-bands. Its absorptivity exceeds 80% at broad angles of incidence up to 40◦.In comparison with existing broadband absorbers using lumped resistors, our proposed absorber exhibits good qualities in terms of compact and easy construction, larger proportional absorber bandwidth, polarization, and wide-incident insensitivity. As a result, the design exhibits promising possibilities for Ku- and X-band applications.

8) Ultra-broadband Thin Metamaterial Absorber for Ku and K Bands Applications [43].

The design of a micromaterial absorber (MMA) for use in broadband applications is presented in this paper. With a suitable overall size and a broad bandwidth, the suggested structure outperforms the previously documented metamaterial absorbers. The absorber is designed to have a broad bandwidth throughout the frequency range of the Ku and K bands. It is composed of a split octagon resonator and an octagon disk. The suggested absorber is made of FR-4 material, which is inexpensive. It has an overall unit cell dimension of 6.5 x 6.5 and a thickness of 1.6. The suggested absorber was simulated using the CST Studio Suite. With approximately 90% absorptions, the suggested absorber offers a broad 14.4 GHz absorption bandwidth throughout the bandwidth range of 12.8–27.5 GHz. Electromagnetic properties, including permittivity (ε), permeability (μ), reflecting index (n), and impedance (z), were retrieved and presented in order to examine the suggested design. The structure's functioning principle is demonstrated by examining and utilizing the input impedance, surface current, and electric field of the structure. The most current MMA published in a magazine was contrasted with the absorber that was proposed. The findings showed that the absorber that was suggested had the largest absorption value and the broadest bandwidth. These findings suggest that the suggested metamaterial absorber offers a viable option for RADAR use.

9)Wide band metamaterial absorber for Ku and K band applications [44].

This study offers a very small, straightforward, double-square-shaped metamaterial absorber (MA) design. The unit cell structure's overall dimensions are 5 x 5 mm2, while the square's dimensions are 1:41 x 1:41 mm2. At 10 dB, a broad band of absorbance covering 14.44 GHz–27.87 GHz, nearly including Ku and K bands, may be achieved using a frequency band of 13.43 GHz. The proposed structure finds use in two domains: satellite communications and radar detection. The entire breadth and half of the maximum bandwidth (from 13.61 GHz - 30.00 GHz) that was obtained is 16.39 GHz. At 16.54, 20.54, & 25.81 GHz, there are three peak bands with absorbance percentages of 99.89%, 99.95%, & 99.96%, respectively. The suggested MA is simulated with ANSYS HFSSv19.1, and a printed circuit board is used to manufacture it on FR4 (flame retardant). For various angles, analysis is conducted under both normal and oblique incidents. Because of manufacturing tolerances, there is not much difference between the simulated and measured absorption results.

10) Wideband Ultra-thin Metamaterial Absorber for Ku &K Band Applications [45].

This paper is based on the ultra-thin wideband absorber for Ku & K-band applications with a 40% fractional bandwidth. The bandwidth of the designed absorber is 8.1 GHz (15.7GHz to 23.8GHz) at absorptivity of more than 90% and 7.3 GHz (16.1 GHz to 23.4 GHz) at absorptivity more than 98%with a center frequency of 19.8GHz. The structure is a single dielectric layer of FR4 having a thickness of 1.6mm. The design of the proposed absorber is based on simple ring geometry with optimized ring width, split width and split angle. The absorber is able to maintain 63% of absorptivity at an incident angle of 45°. Also, the structure observes absorptivity reversal with the variation of the polarization angle from 0° to 90°. A simple miniaturized structure and single-substrate layer with wide bandwidth are the fundamental features of the proposed metamaterial absorber.

11) A co-polarization-insensitive metamaterial absorber for 5G n78 mobile devices at 3.5 GHz to reduce the specific absorption rate [46].

Specific absorption rate (SAR) by next-generation 5G mobile devices has become a burning question among engineers worldwide. 5G communication devices will be famous worldwide due to high-speed data transceiving, IoT-based mass applications, etc. Many antenna systems are being proposed for such mobile devices, but SAR is found at a higher rate that requires reduced for human health. This paper presents a metamaterial absorber (MMA) for SAR reduction from 5G n78 mobile devices at 3.5 GHz. The MMA is co-polarization insensitive at all possible incident angles to ensure absorption of unnecessary EM energies obeying the Poynting theorem for energy conservation and thus ensuring smooth communication by the devices. The unit cell size of the absorber is 0.114 _ making it design efficient for array implementation into mobile devices. This absorber has achieved a minimum of 33% reduction of SAR by applying to the 5G n78 mobile phone model, equivalent to SAR by GSM/LTE/UMTS band mobile phones and making it suitable for SAR reduction from next-generation 5G mobile devices.

12) A filling-factor engineered, perfect metamaterial absorber for multiple applications at frequencies set by IEEE in C and X bands [47].

In this paper, by engineering the filling factor of the resonator of a hybrid frequency selective surface (FSS), a low-profile and application-targeted microwave metamaterial absorber is proposed with polarization and angle insensitivity. The proposed hybrid FSS of the absorber on FR4 substrate comprises four identical concentric copper sub SRRs and a defected copper ground. The square-cut area at the center of the ground and the filling factor of the resonator were tuned to get desired absorption peaks at some IEEE defined frequencies at C and X bands, which any other available perfect metamaterial absorbers cannot obtain. The measurement of the array absorber in anechoic chamber and the equivalent circuit analysis has demonstrated that the filling factor engineering technique illustrated an efficient way to achieve maximum absorptivity with the negative refractive index for perfect absorptions at the desired frequencies. The Wide-angle and polarization insensitivity to both co- and cross-polar waves are described by numerical analysis and EM responses. The thickness and dimension of the unit cell at the lowest operating frequency are 0.022 l and 0.22 l, respectively, and make it subwavelength compact. Besides normal and oblique incidence up to 80_ and 180_, respectively, the absorber showed similar performance for cross-polar waves with an average of 99.5% absorptivity at 4.196 GHz,5.24 GHz, 8.632 GHz, 9.264 GHz, and 10.152 GHz. The absorber has the potential for real-life.

13) A New Approach to Develop a Template Based Load Model that can Dynamically Adopt different types of Non-linear Loads [48].

Both home and business customers employ a variety of loads these days, the majority of which generate enormous harmonics. Despite the fact that most people use more energy-efficient power equipment since electric power consumption is expensive, some individuals are still concerned about the quality of the electricity. To determine how nonlinear loads of various combinations affect a dispersed network's overall power quality, a thorough investigation is necessary. Utilities keep an eye on a number of power quality indicators to ensure the safe functioning of the electrical power network, which consists of transformers, transmission lines, and generators. Developing comprehensive loading models that can dynamically adapt to various load types is the main goal of this work in order to theoretically determine power quality parameters for any combination of loads.

14) Angle-insensitive co-polarized metamaterial absorber based on equivalent circuit analysis for dual band WiFi applications [49].

A novel and systematic procedure to design a co-polarized electromagnetic metamaterial (MM) absorber with desired outputs and resonance frequencies for dual-band WiFi signal absorption is presented. The desired resonance frequencies with expected S parameters’ values were first designed as an equivalent circuit with extensive analysis and then implemented into frequency-selective MM absorber by numerical simulation with precise LRC elements, satisfying least unit cell area (0.08λ),substrate thickness (0.01λ) and maximum effective medium ratio (12.49). The absorber was simulated for the maximum angle of incidence for both the normal and oblique incidences at co-polarization. The absorptions at the desired resonance frequencies were found at a satisfactory level by both simulation and practical measurement along with a single negative value to ensure metamaterial characteristics. The proposed equivalent circuit analysis approach can help researchers design and engineering co-polarization insensitive MM absorbers using conventional split-ring resonators, with perfection in output and desired resonance frequencies without the necessity of lumped elements or multilayer substrates. The proposed metamaterial can be utilized for SAR reduction, crowdsensing, and other WiFi-related practical applications.

15) Design of a Novel Double Negative Metamaterial Absorber Atom for Ku and K Band Applications [50].

The multiband metamaterial (MM) absorber presented in this study is based on a new type of spiral resonator that has an opposing P-shaped, continuous, and dual form The whole wave study shows absorbing ranging from 80.06% to 99.95% at frequency for the Ku and K bands for a number of substrate components with a surface area of 100 mm2.The findings show that, in TEM mode, the absorption rate is constant for a range of polarizing angles and substrate types The design operates like a single negative (SNG) MM absorber employing FR 4 (Flame Retardant 4) on the substrate with a 64 mm2 ground plane in the K band frequency bands (19.75–21.37 GHz) as well as the Ku band resonance bands (15.28–17.07 GHz). However, the Rogers 3035 substrate and 36 mm2 ground plane serve as 83.25% absorption SNG absorbers in Ku band resonance frequencies of 14.64 GHz and 83.69%–94.43 percent absorption DNG absorbers at K band.

It may be used across the K band frequency range of 22.17–26.88 GHz as a DNG absorber with absorption of 92.87%–93.72%, and also in the Ku band during 15.04 GHz as an SNG absorber with 89.77% absorption when paired with a Roger 4300 substrate and a 36 mm2 ground plane. All three substrates were used in the fabrication of the design, and the simulation results were quite similar. When compared to alternative broadband absorbers, the suggested MM absorber demonstrated wide incidence angles when operating in TEM mode.

16) Modified-Segmented Split-Ring Based Polarization and Angle-Insensitive Multi-Band Metamaterial Absorber for X, Ku and K Band Applications [51].

Anovelmodi_ed-segmented split-ring based symmetric metamaterial absorber is introduced in this paper for X, Ku, and K band applications. The perfect absorption was achieved with a total of 1.91 GHz absorption bandwidth using the conventional FR4 substrate without resistive lumped elements. EM waves were applied in TEM mode at both normal and oblique incidence up to 90_ and the same absorptance was found at 11.23 GHz, 14.18 GHz, 17.37 GHz, and 19.18 GHz with the maximum of 85.51%, 99.13%,98.19%, and 90.8% absorptance respectively. This absorption performance was proved for both co- and cross-polarization analysis. Double negative values of permittivity and permeability up to 17.37 GHz and single negative values of either permittivity or permeability at 19.18 GHz were achieved. An equivalent circuit analysis also proved its performance capability, which makes it a perfect metamaterial absorber. Finally, the comparison of the design with recently published works in terms of unit cell size, absorption band, maximum polarization angles, and cross-polarized absorptivity proved it as a better candidate for the potential use as a perfect absorber.

17) Polarization-independent perfect metamaterial absorber for C, X and, Ku band applications [52].

In this paper, a polarization-independent perfect absorber with near-zero index metamaterial(NZIM) property is proposed. Conventional FR4 substrate without any lumped or substrate-embedded elements has been used with a unique patch of the swastika-shaped capacitive gap along with inductive tails at 90-degree rotational symmetry. The simulation results for both the unit cell and the array for co-polarized waves at normal and oblique incidences up to 90_ has shown near unity absorptions at 4.238, 7.836, 10.482, 11.014 and 13.352 GHz along with near zero values of permittivity, permeability, and refractive index. The cross-polarization analysis has proved its perfect absorption capability. The absorber has shown 14 GHz of near-zero refractive index at the entire operating frequency range. The equivalent circuit analysis and measurement of both the array and the unit cell were in good agreement with simulation results, which proved it as a perfect NZIM absorber to enhance antenna gain and directivity and other sensing applications at C, X and Ku band.

18) Rotational symmetry engineered, polarization and incident angle-insensitive, perfect metamaterial absorber for X and Ku band wireless applications [53].

For X and Ku band wireless applications, a square-enclosing split-maze-shaped metamaterial absorber is presented in this study. To make the split-maze construction resistant to cross-polarization and rotationally symmetric, two square metal enclosures were added around it. The proposed absorber has been shown to exhibit the highest absorption across 9.33 GHz, 12.83 GHz, 13.86 GHz, and 15.61 GHz using a single negative permittivity value. The absorber is not affected by the incidence angle of the supplied electromagnetic waves for both regular and oblique occurrences up to 180 degrees. Furthermore, because of the symmetry of the patch, it was shown to be resistant to both co- and cross-polarization. A detailed equivalent circuit analysis described the electromagnetic behavior inherent in the metamaterial structure, and the circuit outputs matched the simulation findings. Finally, the metamaterial for the unit cells and the array was measured after production and confirmation of the modeling results. Particularly for sensing, electromagnetic energy harvesting, EM coupling reduction, and antenna gain increase, the suggested MMA is appropriate for wireless applications in devices.

19) Wide Bandwidth Angle- and Polarization-Insensitive Symmetric Metamaterial Absorber for X and Ku Band Applications [54].

This work proposes a symmetric metamaterial (MM) absorber for the X and Ku bands that is broad bandwidth, angle-, and polarization-insensitive. The suggested unit cell exhibits strong absorption at various polarizing angles for regular and oblique incident in TEM mode because of structural symmetry. To increase the bandwidth, the unit cell was modified to include a four-fold resonator. Measurements and full-wave simulations are used to assess the suggested absorber's performance. At normal incidence, there is nearly no difference between the simulated and observed absorptions at 11.31 GHz, 14.11 GHz, 14.23 GHz, and 17.79 GHz, respectively, with 94.63%, 95.58%, 97%, and 75.58%. The absorptions for these frequencies at 45° are 95.47%, 97.2%, 97.12%, and 75.29%, in that order. The absorptions at 90° are comparable to those at 45°, with the exception of 98.15% at 14.21 GHz. The unit cell's metamaterial properties were revealed by the negative refractive index, which was obtained for all these angle and resonance frequencies due to either permeability or permitibity being discovered to be negative. A total absorption bandwidth of 1.42 GHz was attained, which is superior than recent similar efforts using FR4 substrate. Additionally, there was broad angle of incidence insensitivity as much as 90° and significant absorptivity. To increase the bandwidth, the unit cell was modified to include a four-fold resonator. Measurements and full-wave simulations are used to assess the suggested absorber's performance.

20) A Perfect Metamaterial Absorber [55].

We present the design for an absorbing metamaterial element with near unity absorbance. Our structure consists of two metamaterial resonators that couple separately to electric and magnetic _elds so as to absorb all incident radiation within a single unit cell layer. We fabricate, charac-terize, and analyze a metamaterial absorber with a slightly lower predicted absorbance of 96%. This achieves a simulated full width at half maximum (FWHM) absorbance of 4% thus making this material ideal for imaging purposes. Unlike conventional absorbers, our metamaterial consists solely of metallic elements. The underlying substrate can therefore be chosen independently of the substrate's absorptive qualities and optimized for other parameters of interest. We detail the de- sign and simulation process that led to our metamaterial, and our experiments demonstrate a peak absorbance greater than 88% at 11.5 GHz.

CHAPTER 3

Methodology and Design Process

3.1 Introduction

A method represents a planned strategy for completing a task. This might be related to the procedures that a business or sector follows, the methods employed in a certain investigation, or the manner in which a specific operation was completed. Occasionally, the study of these processes is referred to as "methodology" rather than the techniques themselves.

A collection of several procedures, each applied to various aspects of the entire spectrum of methodology, can be conceptualized as methodology. The two components of research are qualitative and quantitative.

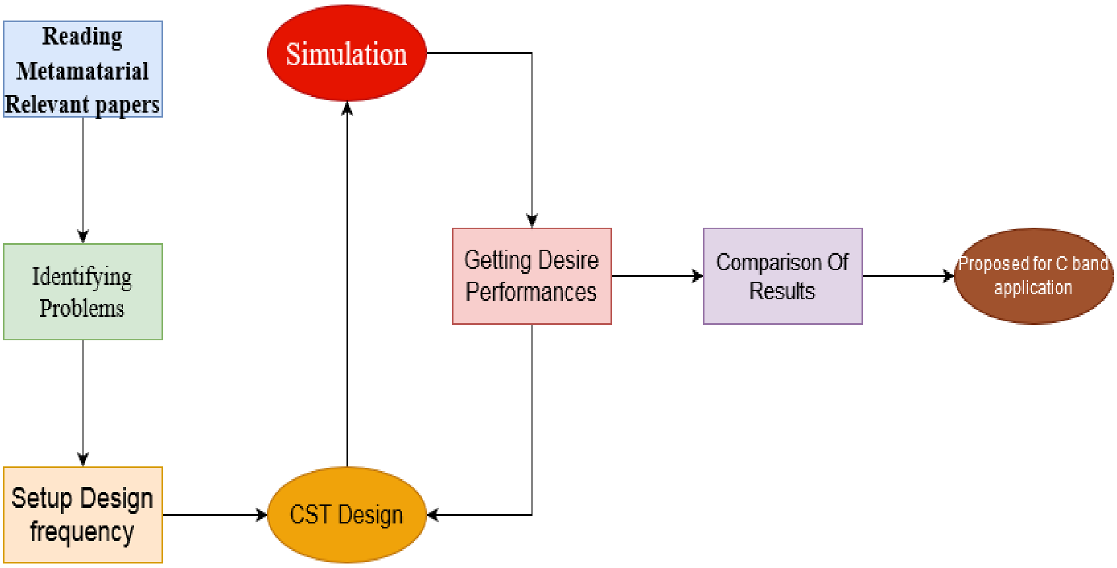


Figure 3.1 Flowchart

The flowchart is defining below:

Reading Metamaterial Relevant papers:

First of all, we have to read those types of papers which is related metamaterial absorber. We can get a primary idea from those paper. If i read metamaterial relevant papers then I can explain my design very well. Because in different types of papers I can find different types of idea. After reading several metamaterial papers, I have gather some information on it and applied it on my thesis.

Identifying Problems:

Secondly, we have to identify those paper problems which are related with metamaterial absorber. Then we can also see our problems when we will go for our paper writing.

Setup Design Frequency:

Thirdly, we will fix e frequency which we can simulate our metamaterial absorber. If I fix the frequency of my design then i will get a good result of my simulation of design.

CST Design:

After fixing the frequency we will design a metamaterial absorber to CST studio suite software. I can design various types of design in this CST studio software, which are preferable for our design.

Simulation:

After design a metamaterial absorber we have to simulate our design. By the simulation I can get different types of resonance frequency, Permitivity, Permeability, Refractive index and Absorption of my design.

Getting Desire Performances:

Completing the simulation then we will check the performance of metamaterial absorber. If the simulation result is better than I will get a good performance from this.

Comparison of Results:

After getting results we have to compare the results with the previous paper results for a good metamaterial absorber. Because if I find the comparison result then I can try to get more better result from others results.

3.2 Methodology of the design

"Research design" refers to the comprehensive strategy developed to answer the research questions of the study. The study materials, such as the subject of the research, independent and dependent variables, the design of the experiment, and, if relevant, data collection techniques and the statistical analysis strategy, are outlined in the research project design.

Methodology of this study:

- Investigate metamaterial absorbers.
- Research the characteristics of the metamaterial absorber.
- Examine the steps involved in designing a metamaterial absorber.
- Determine the essential parameters for creating a metamaterial absorber design.
- To ascertain the possible applications of this work.
- For this design, get proficient with the CST software tools.

3.3 Analysis Method

First, a brief discussion of the ideal MMA's design method is given. In the first section, the design specifications of an ideal MMA are covered. Three distinct structural approaches to a unit cell structure for polarization insensitivity are shown. Secondly, three distinct structures for three distinct applications are used to describe the design approach towards frequency-targeted as well as co-polarization-insensitive metal-halide semiconductors (MMA).

We modeled the absorbers under study using a CST microwave studio, depending on the finite difference time domain. The corresponding circuit design method for those absorbers is then covered, along with the required formulas.

Step1: Design, simulation and analysis of parameters

Step2: Create the ideal metamaterial absorber. The FR-4 substrate and 9*9 mm2 metamaterial are used in this design.

Step3: Achieve near-perfect absorption by designing metamaterial absorbers using DNG or SNG.

Step4: Design a metamaterial absorber with selected frequencies that function together.

Step5: To assess the metamaterial absorption property, analyze the specific absorption rate, radiation performance, and reflection coefficient, among other factors.

Step6: Final step, Conclusion and recommendation.

3.4 Metamaterial Absorber Design

Two split ring and two split square ring resonance devices were used in the creation of the metamaterial structure. Copper was used to design the resonating layer, and its dielectric constant was 5.8 e+007 s/m. The substrate layer was designed using FR-4 dielectric material. The MMA unit cell's structure is displayed in Fig. 1. Copper was also used in the MMA's rear layer to stop the propagating waves from passing through the structure. Copper is also used in the patch The copper thickness is 0.035 mm, the dielectric thickness is 4.3 mm, and the FR-4 thickness is 1.6 mm. The table contains a list of all the geometrical parameters. We used three types of software to design a metamaterial absorber. They are CST,MATLAB and ORIGIN. The MMA unit cell is modeled and simulated using CST Studio Suite, a professional full-wave simulation tool.

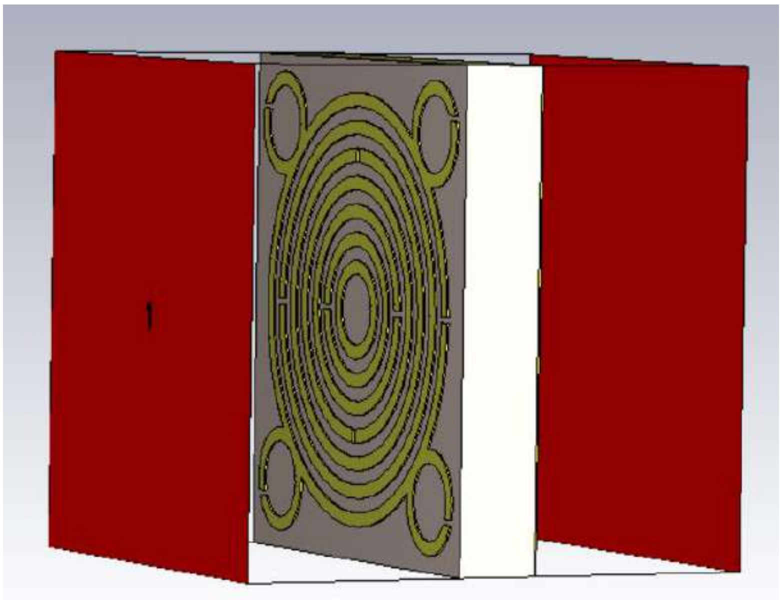
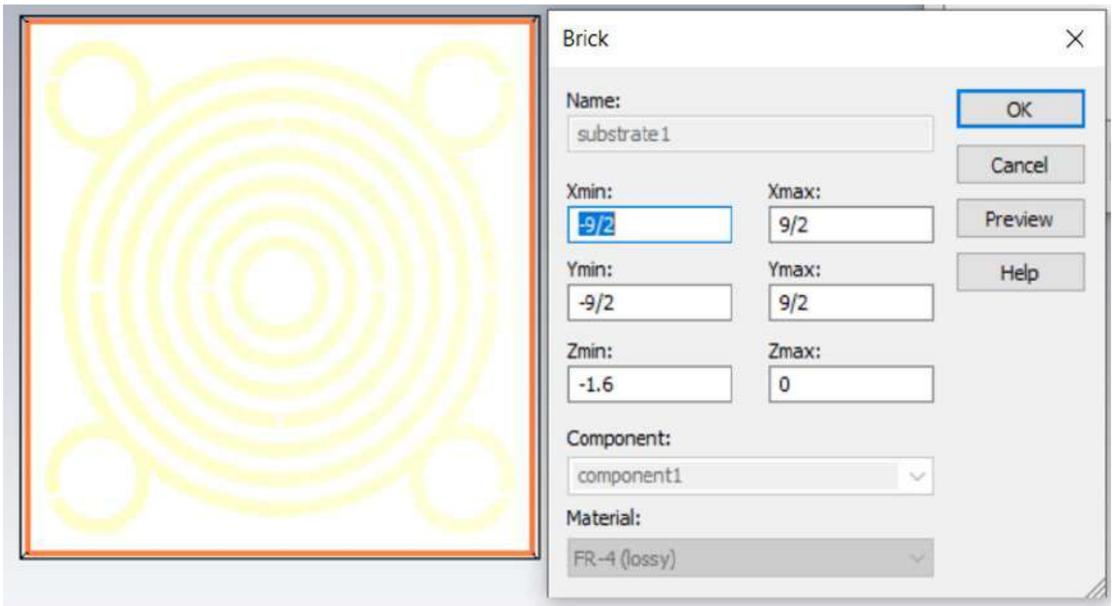


Figure 3.2 Metamaterial Absorber Design

In order to create a metamaterial absorber, we employ the 3D coordination system in the simulation program CST microwave studio. In my design, the substrate is 9 by 9 mm2, the FR-4 is 1.6 mm thick, the copper is 0.035 mm thick, and the dielectric thickness is 4.3 mm.

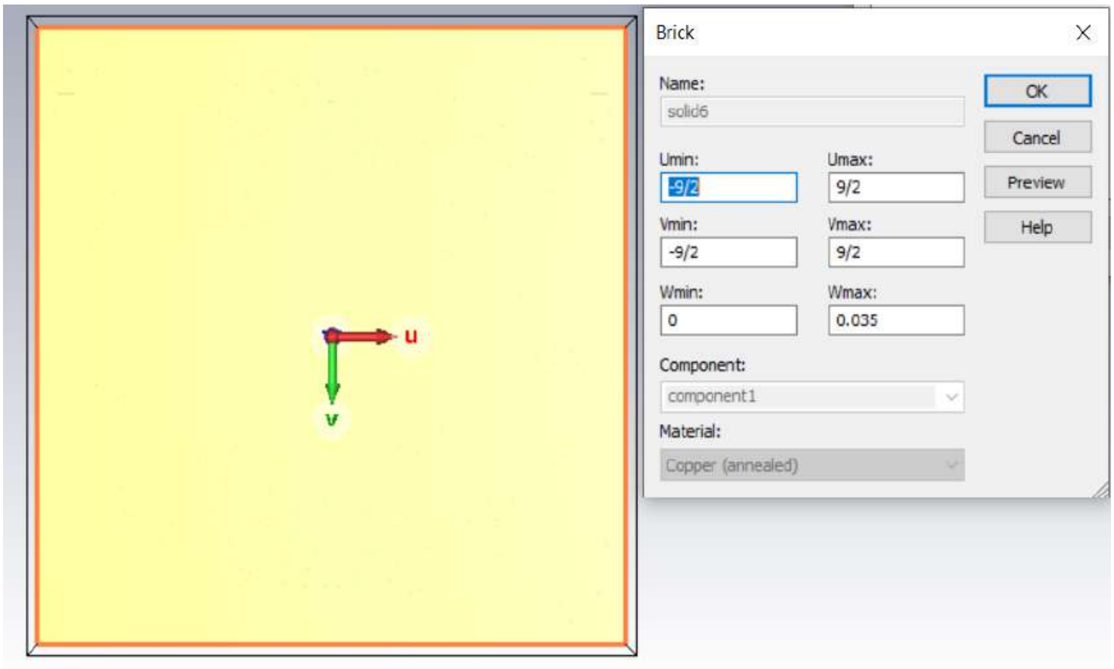
3.4.1 Substrate, Ground

The measurement of the substrate and Ground is 9×9 〖mm〗^2. The copper thickness is 0.035 mm, the dielectric thickness is 4.3 mm, and the FR-4 thickness is 1.6 mm. I show my details of design step below:



Name: substrate1
Xmin: -9/2
Xmax: 9/2
Ymin: -9/2
Ymax: 9/2
Zmin: -1.6
Zmax: 0
Component: component1
Material: FR-4 (lossy)

Figure 3.3 Substrate



Name: solid6
Umin: -9/2
Umax: 9/2
Vmin: -9/2
Vmax: 9/2
Wmin: 0
Wmax: 0.035
Component: component1
Material: Copper (annealed)

Figure 3.4 Ground

3.4.2 Final Patch view or (Final Design)

This is my final patch view of my design. I mentioned their of my every patch view. In every patch I got different types of resonance frequency, permittivity, permeability, refractive index and absorption rate, surface current, reflectance, reflection co-efficient and Transmission of my design. In figure 3.5 i showed my final design.

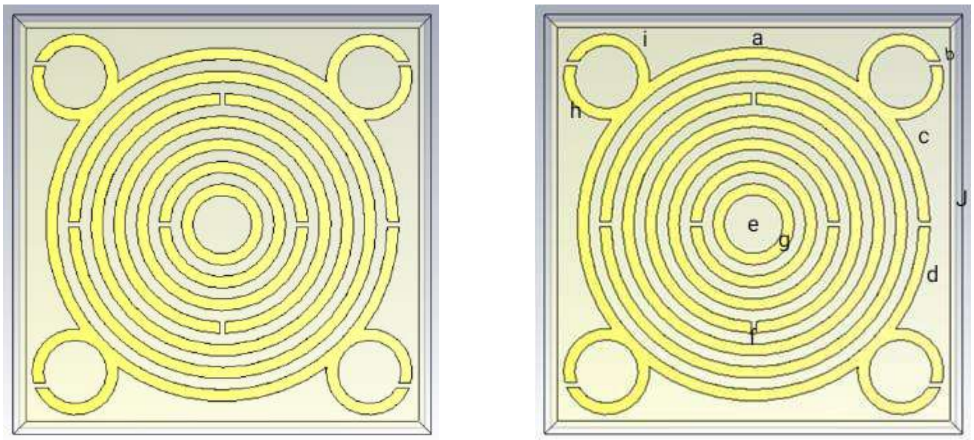


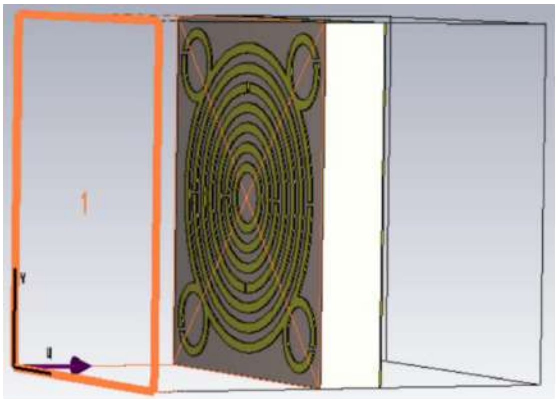
Figure 3.5 Final Design

TABLE I. PARAMETER OF THE MMA STRUCTURE

Parameter	Size(mm)	Parameter	Size(mm)
a	4.61	f	0.10
b	0.11	g	1.30
c	0.28	h	1.57
d	2.35	i	1.88
e	0.10	j	9.00

Ports:

In this metamaterial design there are some ports. Their line text is Z negative. In this ports Xmin is -4.5, Xmax is 4.5 and Ymin is -4.5, Ymax is 4.5. Their position Zpos is 4.4437126176471.



General
Name: 1
Folder:
Label:
Normal: ○ X ○ Y ● Z
Orientation: ○ Positive ● Negative
Text size:
☑ Limit text size to port area

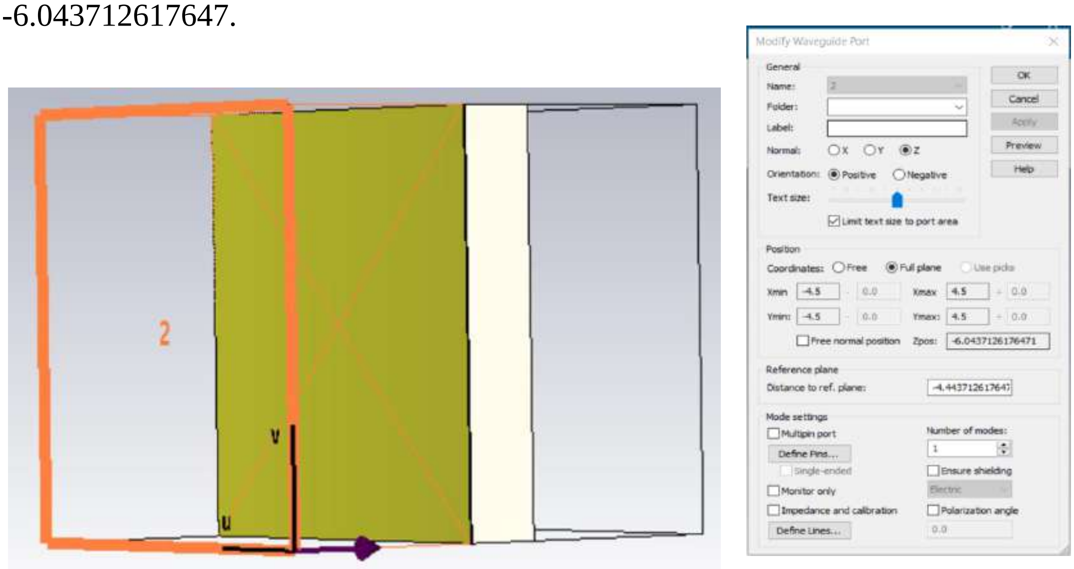
Position
Coordinates: ○ Free ● Full plane ○ Use picks
Xmin: -4.5 - 0.0 Xmax: 4.5 + 0.0
Ymin: -4.5 - 0.0 Ymax: 4.5 + 0.0
☐ Free normal position Zpos: 4.4437126176471

Reference plane
Distance to ref. plane: -4.44371261764?

Mode settings
☐ Multipin port
☐ Single ended
☐ Monitor only
☐ Impedance and calibration
Number of modes: 1
☐ Ensure shielding
Electric
☐ Polarization angle
0.0

Figure 3.6 Port 1

In this metamaterial design there are some ports. Their line text are Z negative. In this ports Xmin is -4.5, Xmax is 4.5 and Ymin is -4.5, Ymax is 4.5. Their position Zpos is -6.043712617647.



Modify Waveguide Port

General
Name: 2
Folder:
Label:
Normal: ○ X ○ Y ● Z
Orientation: ● Positive ○ Negative
Text size:
☑ Limit text size to port area

Position
Coordinates: ○ Free ● Full plane ○ Use picks
Xmin -4.5 - 0.0 Xmax 4.5 + 0.0
Ymin: -4.5 - 0.0 Ymax: 4.5 + 0.0
☐ Free normal position Zpos: -6.0437126176471

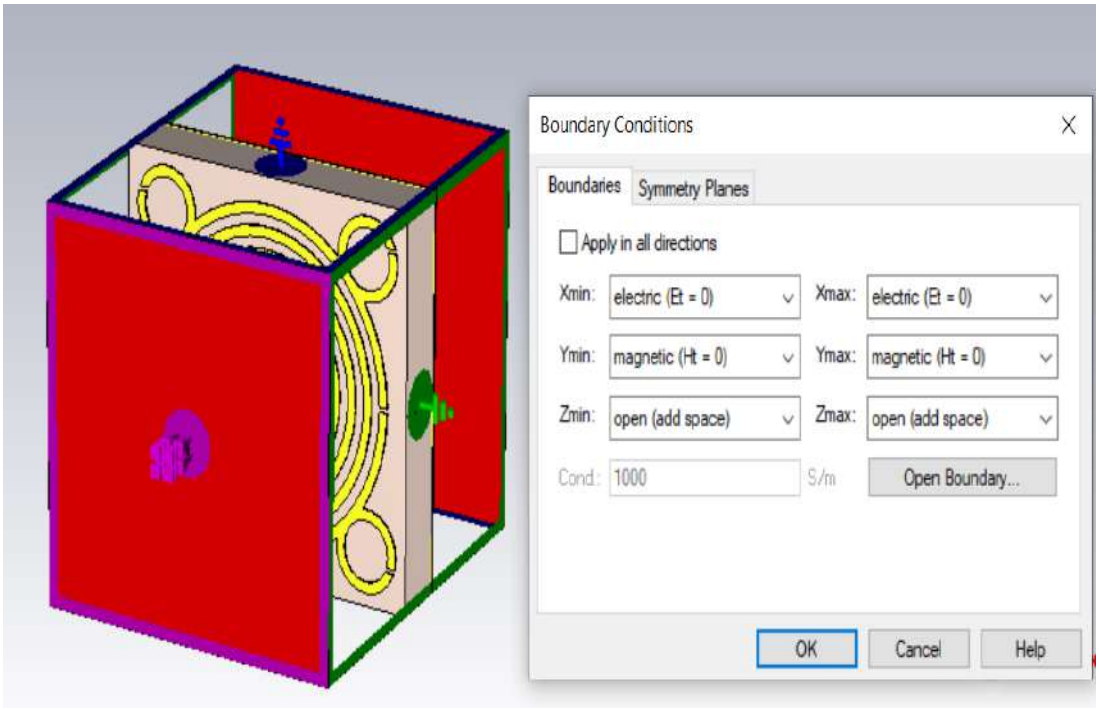
Reference plane
Distance to ref. plane: -4.44371261764?

Mode settings
☐ Multipin port
Define Pins...
☐ Single-ended
☐ Monitor only
☐ Impedance and calibration
Define Lines...
Number of modes: 1
☐ Ensure shielding
Electric
☐ Polarization angle
0.0

Figure 3.7 Port 2

3.4.3 Waveguide Port

A critical decision in simulation is the selection of the waveguide port. This uses a pair of waveguide ports, a positive and a negative one. It must flow from the metamaterial's one side to its other.



Boundary Conditions

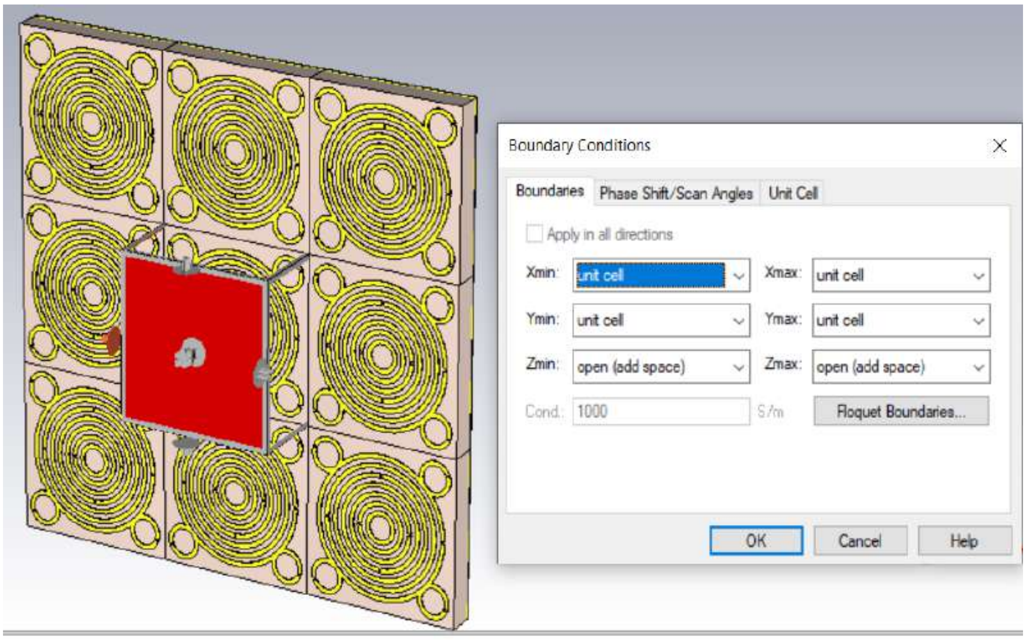
Boundaries | Symmetry Planes

☐ Apply in all directions
Xmin: electric (Et = 0) Xmax: electric (Et = 0)
Ymin: magnetic (Ht = 0) Ymax: magnetic (Ht = 0)
Zmin: open (add space) Zmax: open (add space)
Cond.: 1000 S/m

Figure 3.8 Waveguide Port

3.4.4 Array design

To achieve the necessary absorption qualities across a certain frequency range, the unit cell design of a metamaterial absorber includes modifying the layout, composition, and arrangement of the unit cells. Engineered structures referred to as metamaterial absorbers are capable of selectively absorbing electromagnetic waves, which are typically found in the optical and terahertz ranges of the microwave spectrum.



Xmin: unit cell
Xmax: unit cell
Ymin: unit cell
Ymax: unit cell
Zmin: open (add space)
Zmax: open (add space)
Cond.: 1000 S/m

Figure 3.9 Unit Cell Design

3.4.5 Matlab

I use matlab software for my design. MATLAB is a programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics.

Matlab uses for Developing algorithms, Performing linear algebra that is linear, Graph plotting for larger data sets, Data visualization and analysis, Numerical Matrix Computation. Engineers and scientists need a programming language that lets them express matrix and array mathematics directly.

Linear algebra in MATLAB is intuitive and concise. The same is true for data analytics, signal and image processing, control design, and other applications.

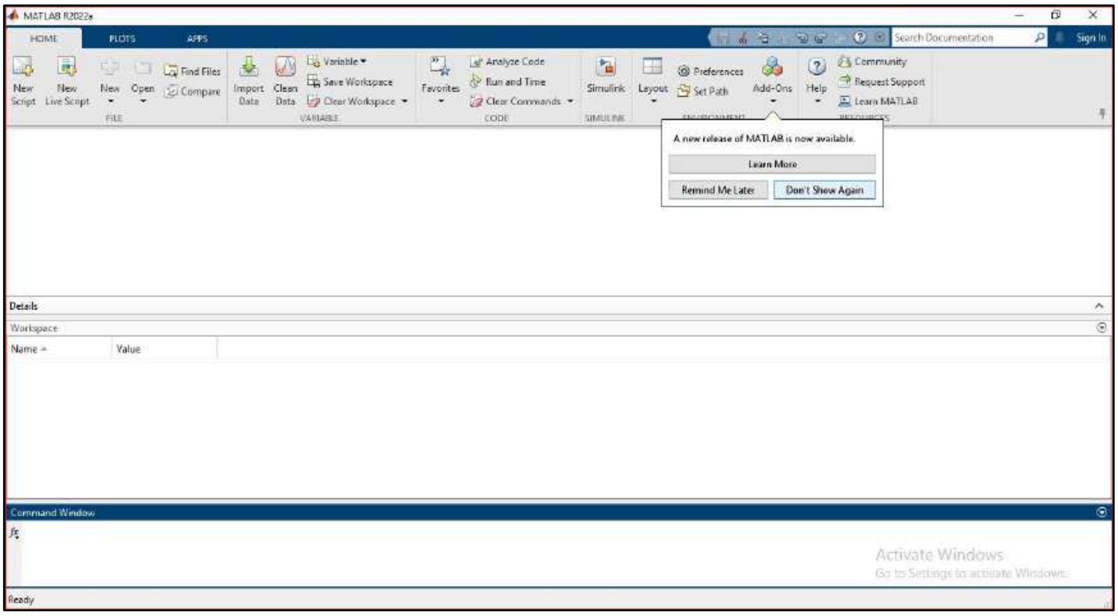
MATLAB is a high-level programming language designed for engineers and scientists that expresses matrix and array mathematics directly.

I can use MATLAB for everything, from running simple interactive commands to developing large-scale applications. There are various types of MATLAB. Numeric arrays, characters and strings, tables, structures, and cell arrays; data type conversion. By default, MATLAB® stores all numeric variables as double-precision floating-point values.

Matlab is a proprietary software developed by MathWorks, which provides a high-level programming language and an interactive environment primarily designed for numerical computing, algorithm development, data analysis, and visualization. Here are some key aspects of Matlab software: Matlab provides an interactive environment where users can execute commands, perform computations, and visualize results in real-time. The command window allows users to enter Matlab commands and scripts, while the integrated development environment (IDE) provides tools for editing and debugging code.

Matlab uses its own programming language, which is optimized for matrix and vector operations. It supports procedural, functional, and object-oriented programming paradigms and includes features such as control flow statements, functions, and data structures. Matlab is particularly well-suited for numerical computing tasks, such as solving linear algebraic equations, optimization problems, and differential equations. It includes a comprehensive library of built-in functions and toolboxes for numerical analysis and scientific computing. Matlab offers powerful tools for data analysis, manipulation, and visualization. It provides functions for importing and exporting data from various file formats, statistical analysis, machine learning, and creating publication-quality plots and graphs. Toolboxes: Matlab comes with a wide range of toolboxes that extend its functionality for specific application areas such as signal processing, image processing, control systems, communications, and more. These toolboxes provide specialized functions, algorithms, and graphical interfaces tailored to specific domains. Matlab allows users to deploy their applications as standalone executables, web applications, or shared libraries. This enables users to distribute their Matlab-based solutions to end-users who may not have Matlab installed. Matlab can be integrated with other programming languages and software tools. It provides interfaces for calling external libraries and executing code written in languages such as C/C++, Java, Python, and .NET. It also supports interoperability with popular software packages such as Excel, LabVIEW, and Simulink.

Matlab provides comprehensive documentation, including help files, examples, and tutorials, to assist users in learning and using the software effectively. Additionally, MathWorks offers technical support, training programs, and online forums where users can seek help and collaborate with other Matlab users. Matlab is a versatile and powerful tool for engineers, scientists, and researchers working in fields such as mathematics, engineering, physics, finance, and biology, among others. Its ease of use, extensive functionality, and rich ecosystem of toolboxes make it a popular choice for numerical computation and algorithm development tasks.



A new release of MATLAB is now available.

Figure 3.10 MATLAB software

3.4.6 Origin Pro

Origin is a proprietary computer program for interactive scientific graphing and data analysis. Origin is a proprietary computer program for interactive scientific graphing and data analysis. It is produced by OriginLab Corporation, and runs on Microsoft Windows. It has inspired several platform-independent open-source clones and alternatives like LabPlot and SciDAVis. Graphing support in Origin includes various 2D/3D plot types. Data analyses in Origin include statistics, signal processing, curve fitting and peak analysis. Origin's curve fitting is performed by a nonlinear least squares fitter which is based on the Levenberg–Marquardt algorithm. Origin imports data files in various formats such as ASCII text, Excel, NI TDM, DIADem, NetCDF, SPC, etc. It also exports the graph to various image file formats such as JPEG, GIF, EPS, TIFF, etc.

There is also a built-in query tool for accessing database data via ADO. Origin also has a scripting language (LabTalk) for controlling the software, which can be extended using a built-in C/C++-based compiled language (Origin C). Other programming options include an embedded Python environment, and an R Console plus support for reserve. OriginPro is a proprietary software developed by OriginLab Corporation, designed primarily for scientific and engineering data analysis and graphing. Here are some key aspects of OriginPro software:

OriginPro provides a wide range of tools for data analysis, including statistical analysis, curve fitting, peak analysis, signal processing, image analysis, and more. It offers a comprehensive set of built-in functions and algorithms for performing advanced data processing tasks. OriginPro offers powerful graphing and visualization capabilities, allowing users to create a variety of 2D and 3D plots, graphs, and charts. It provides extensive customization options for adjusting plot styles, annotations, axes, and legends to create publication-quality figures.

OriginPro supports importing data from a variety of file formats, including Excel, CSV, MATLAB, and ASCII files. It also allows users to export their analysis results and graphs to various formats for sharing and presentation purposes. OriginPro includes a built-in programming language called LabTalk, which allows users to automate tasks, create custom analysis routines, and extend the software's functionality. Additionally, OriginPro supports scripting in languages such as Python, R, and MATLAB, enabling users to integrate their workflows with other software tools. It can be integrated with other software tools and programming languages through its built-in scripting and automation capabilities. It provides interfaces for calling external functions and libraries, facilitating interoperability with MATLAB, Python, C/C++, and other programming languages. OriginPro allows users to create publication-quality reports and documents by combining analysis results, graphs, and annotations into customizable layouts. It offers tools for adding text, images, tables, and equations to create comprehensive scientific documents.

OriginPro offers optional add-on modules that extend its functionality for specific applications such as peak fitting, spectroscopy, kinetics, and chemometrics. These modules provide specialized tools and analysis techniques tailored to the needs of users in various scientific and engineering disciplines.

OriginPro has an active user community and provides technical support through online forums, tutorials, documentation, and training programs. Users can also access a wide range of resources, including sample projects, templates, and example scripts, to help them get started with the software.

Overall, OriginPro is widely used by scientists, engineers, researchers, and educators for analyzing and visualizing experimental data, conducting research, and preparing scientific publications. Its intuitive interface, extensive functionality, and customizable features make it a popular choice for data analysis and graphing in various fields of science and engineering.

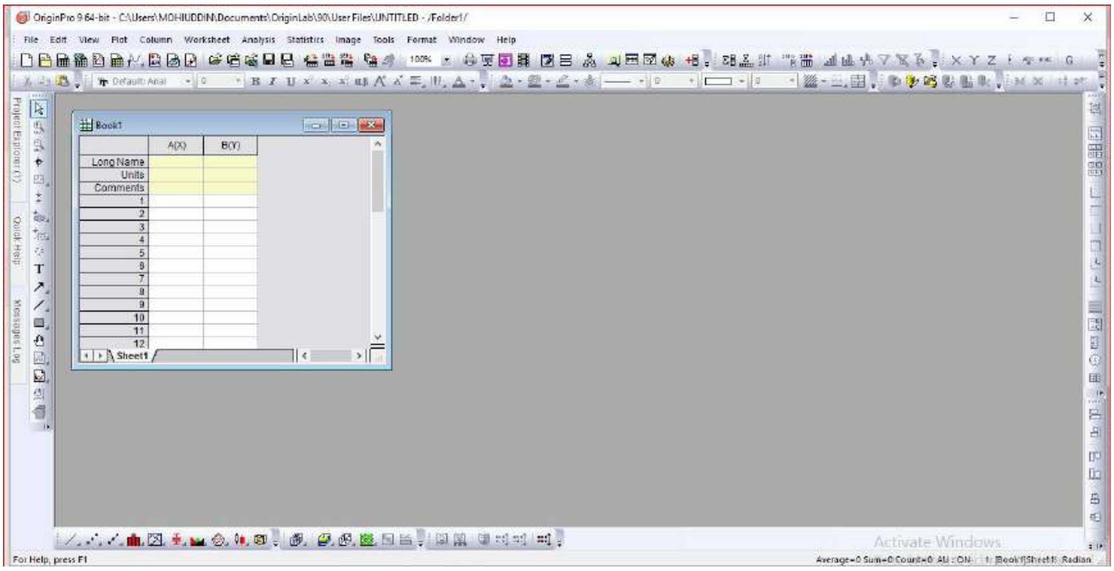


Figure 3.11 OriginPro software

3.4.7 How to get Surface Current

In surface current I simulated in CST software. We get three types of result in there. 1D, 2D and 3D results. In 2D and 3D results I can find my surface current. After this I fixed and setup some frequency to get my absorber from this in surface current.

I got various types of surface current. it is observed that the current flow in each of the split ring resonators are in opposite directions. This because, the skin effect on the copper strip causes a sustainable electrostatic condition and the opposing current flows are unequal to each other. When the current flowing in the two directions are equal, the fields will internally cancel each other, and a stop band will occur.

In addition, a powerful electric field is generated in the gaps between the rings and this effect extends to the center of the design at C-band frequencies. On the other hand, at Ku-band frequencies, the design also has a powerful electric field in gaps between the rings, but the electric field is reduced before reaching the fifth inner circular ring.

Usually, sole dielectric substrate which also known as electrical insulator, do not have free electrons like metal materials. Since the proposed design has metal circular rings arrangement on dielectric substrate, the exist electron oscillations at interface between metal and dielectric materials are de-localized. In other word, across the interface the real part of dielectric function changes sign.

Surface current typically refers to the movement of water near the surface of oceans, seas, lakes, or rivers. These currents are driven by a variety of factors, including wind, temperature gradients, tides, and the Earth's rotation. Surface currents play a crucial role in redistributing heat, nutrients, and marine life throughout the world's oceans and can have significant impacts on weather patterns and climate. Surface currents are primarily driven by winds blowing over the surface of the water. Wind friction causes water molecules to move, generating currents that flow in the direction of the prevailing winds. The major wind belts, such as the trade winds, westerlies, and polar easterlies, influence the direction and strength of surface currents in different regions of the world's oceans. Surface currents tend to form large circular patterns called gyres in the major ocean basins. These gyres are driven by the combined effects of wind, the Earth's rotation (Coriolis effect), and the shape of the ocean basins.

The movement of surface water induced by wind stress doesn't directly flow in the direction of the wind due to the Coriolis effect. Instead, it moves at an angle to the wind, creating a phenomenon known as Ekman transport. This causes surface water to accumulate in the center of gyres, leading to the formation of oceanic convergence zones and divergence zones.

Surface currents can cause vertical movements of water known as upwelling and downwelling. Upwelling occurs when surface water is displaced away from the coast, causing cold, nutrient-rich water from deeper layers to rise to the surface. Downwelling, on the other hand, involves the sinking of surface water, often occurring in regions of oceanic convergence.

3.4.6 Walkthrough of the Metamaterial Absorber

This design has been done from scratch by learning CST to evaluating the many research papers and comparing them for better result. A flowchart has been given below to show the whole walkthrough of the metamaterial absorber design and evaluation of it.

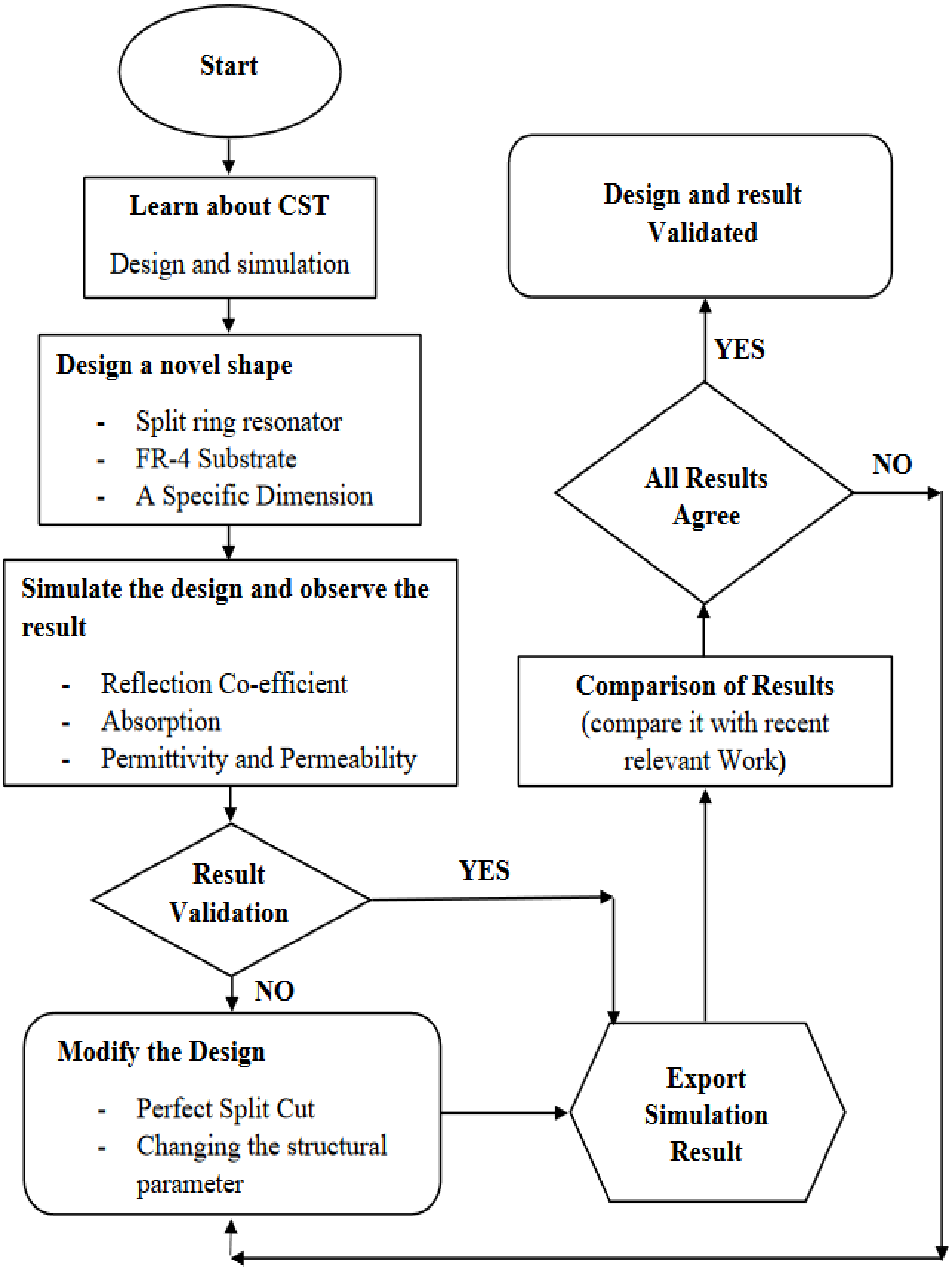


Figure 3.12 Flowchart of the metamaterial absorber

CHAPTER 4

Simulation & Result Analysis

4.1 Introduction

An artificial substance known as a metamaterial absorber (MMA) possesses special electromagnetic characteristics not present in naturally generated materials and is capable of manipulating electromagnetic waves. Metamaterials are synthetic structures composed of subwavelength building units arranged in periodic arrays. Owing to these materials' potential applications in a range of sectors, including energy harvesting, interaction, image processing, and sensing, a lot of research has been conducted on them in recent years. Effective permittivity and permeability—which are different from those of ordinary materials—define the characteristics of metamaterials.

The concept of metamaterials was first put forth by Veselago in 1968, and since then, the field's research has developed swiftly. The potential uses of multiband metamaterial absorbers in multiband sensing and imaging have led to their proposal and intensive study in recent years[53]. The capacity of multiband metamaterial absorbers to absorb a broad range of frequencies has drawn a lot of interest in recent years. We propose to develop a metamaterial absorber structure that utilizes multiband absorbers (MMAs) in the form of a square split-enclosed labyrinth maze. The multi-layer metamaterial construction is intended for usage in frequency ranges such as sensing.

We get the multiband (8.903094GHz, 14.102GHz, 14.606GHz, 20.996GHz & 21.68GHz) resonance frequencies. Regarding tuning capabilities, absorption efficiency, and bandwidth, there is still opportunity for development. For multiband metamaterial absorbers to function as well as possible, more research is therefore required. Metamaterials are investigated for sensing purposes in addition to their ability to absorb electromagnetic waves [54].

4.2 MMA Result Analysis

The metamaterial absorber characteristics of the suggested absorber have been demonstrated at the resonance frequency (Fig. 1), which is 8.903094 GHz, 14.102

GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz. In X, K and Ku band frequencies finding significant applications in satellite communication, terrestrial microwave communication and radar communication. The central parallel stripes were crucial because they provided the patch's appropriate inductance, along with the required resistance and associated capacitance, to provide a resonance frequency.

4.2.1 Reflection Co-efficient

At the resonance frequencies of 8.903094 GHz, 14.102 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz, the developed absorber has demonstrated the necessary metamaterial absorber qualities. It was essential to adjust the frequency of resonance at the X, K, and KU bands using the center parallel strips. This involved obtaining the patch's requisite inductance, resistance, and related capacitance.

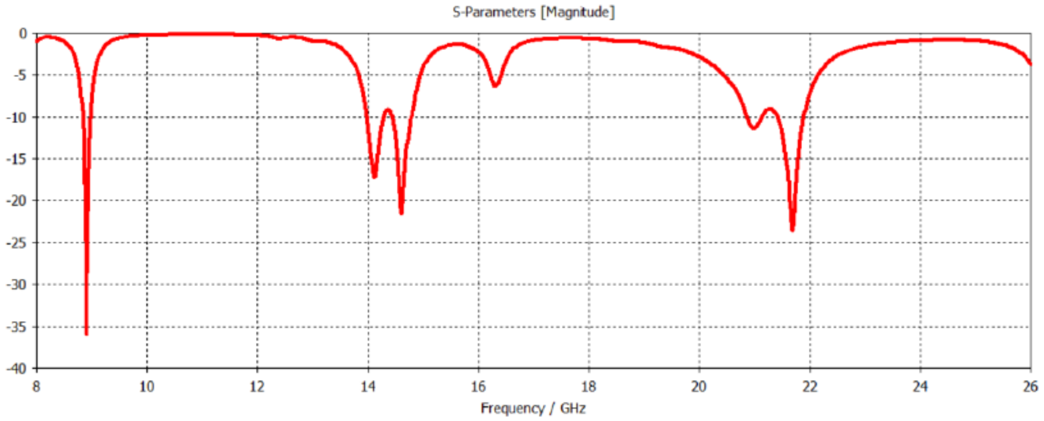


Figure 4.1 Reflection Co-efficient

4.2.2 Reflectance

The desired resonance frequency is not being reflected, as seen in Figure 4.2 where R_1,1 is magnitude.

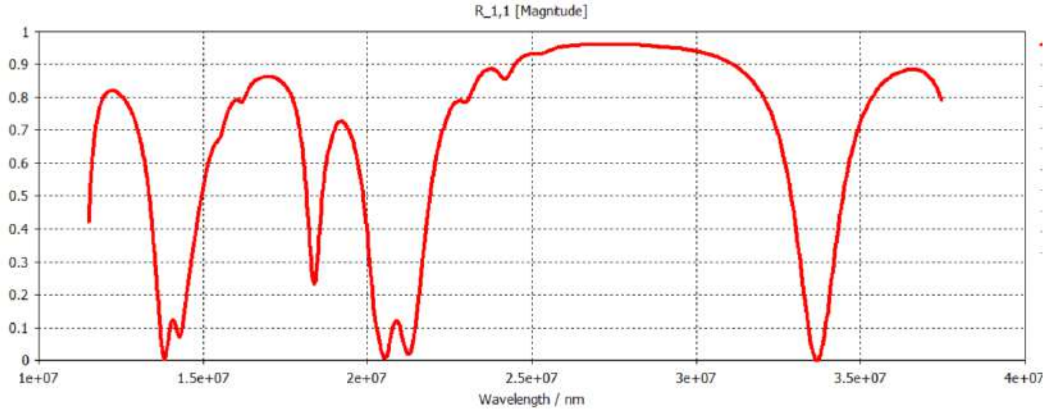


Figure 4.2 Reflectance

4.2.3 Transmission

Metamaterial transmission lines are one-dimension structures. Their performances can be roughly analyzed by the circuit models, and the relation between them and band-pass filters is discussed as well. There are many applications of metamaterial transmission lines due to their excellent performance.

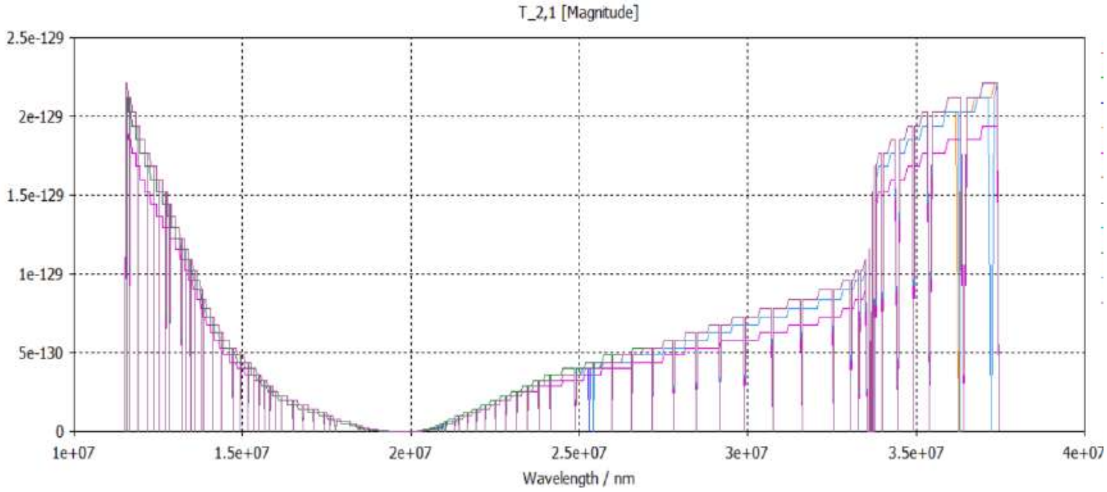


Figure 4.3 Transmission

4.2.4 Absorption

The suggested MMA's absorption behavior for various frequency square split-contained labyrinth maze-shaped structures is depicted in Figure 4.4 . According to both computed and observed measurements, the peak resonance frequencies are 14.102 GHz, 21.68 GHz, 20.996 GHz, 14.606 GHz, and 8.903094 GHz.

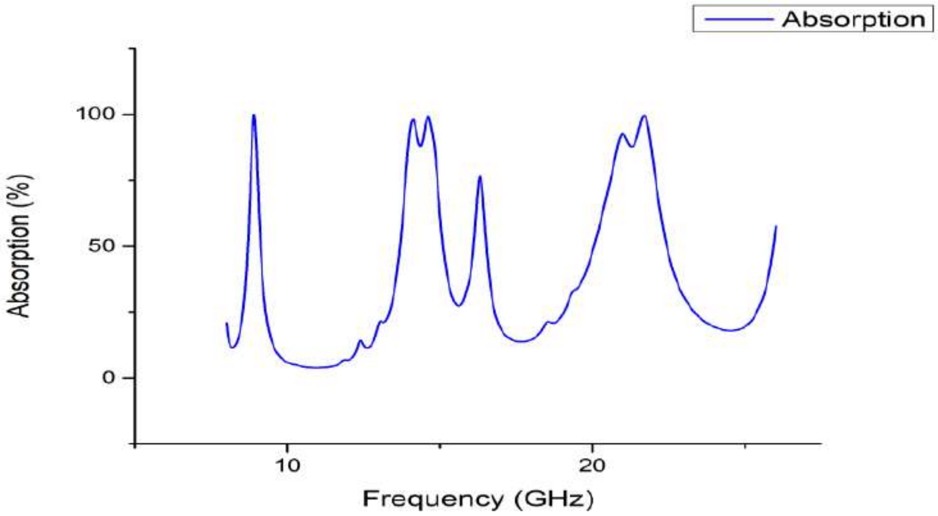


Figure 4.4 Absorption

4.2.5 Permittivity

The permittivity at various resonance frequencies (8.903094 GHz, 14.102 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz) is displayed in Figure 4.5. The permittivity value is positive, as can be seen.

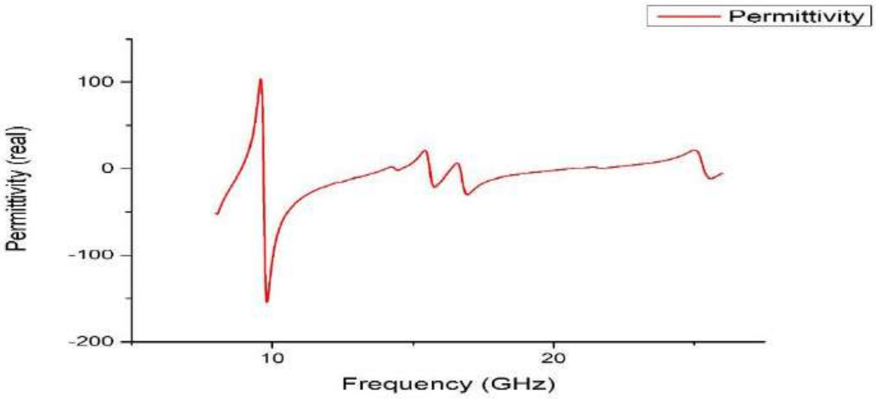


Figure 4.5 Permittivity (ε)

4.2.6 Permeability

Figure 4.6 displays the permeability at several resonance frequencies: 14.102 GHz, 8.903094 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz. Permeability value is positive, as can be seen.

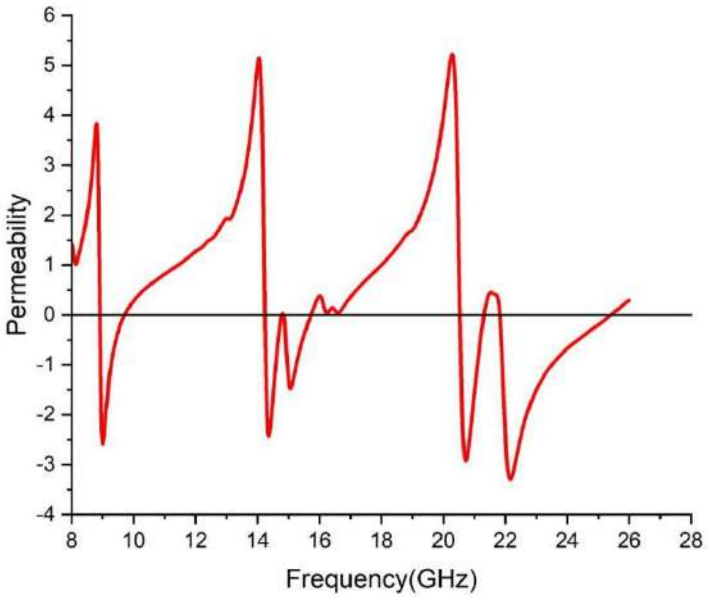


Figure 4.6 Permeability (μ)

4.2.7 Refractive Index

Show the resultant refractive index in Fig. 4.7. In this case, zero is the refractive index. The refractive index is known as the absolute refractive index when light travels from a vacuum to another medium.

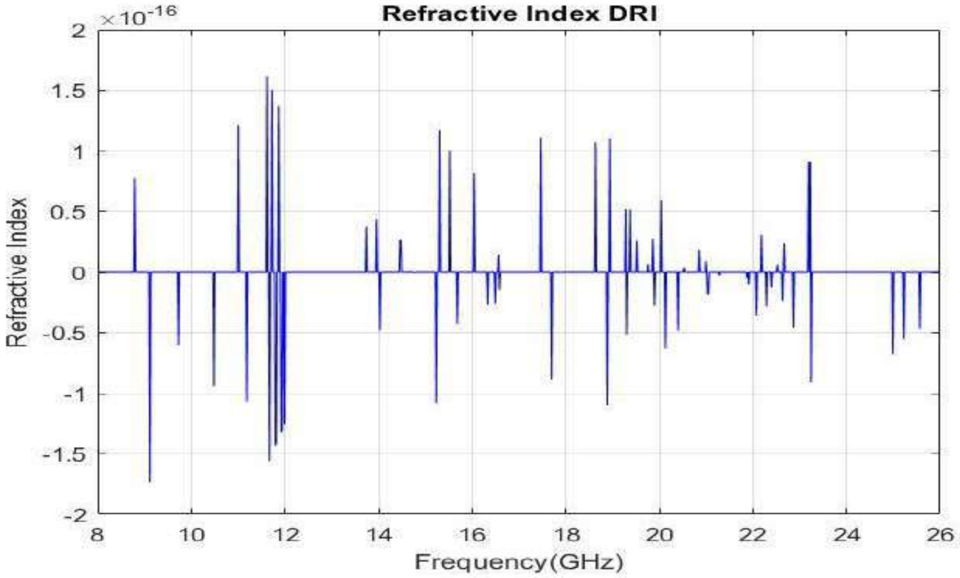


Figure 4.7 Refractive Index

TABLE II. CHARACTERISTICS OF THE PROPOSED ABSORBER IN TERMS OF MATERIALS

Resonance Frequencies (GHz)	**Real permittivity (ε)**	**Real permeability (μ)**	**Refractive Index**	**Absorption (%)**
8.903094 GHz	-0.066121483	0.06218706	0	99.97419467
14.102 GHz	0.713577992	-1.029702207	0	98.11714259
14.606 GHz	0.194573521	-0.140068627	0	99.2870091
20.996 GHz	0.768540695	-1.581067704	0	92.75448222
21.68 GHz	0.364255476	-0.366860817	0	99.55493077

4.2.8 Surface Current

Surface current is a current flowing in a plane, and has units of charge per unit time per unit length.

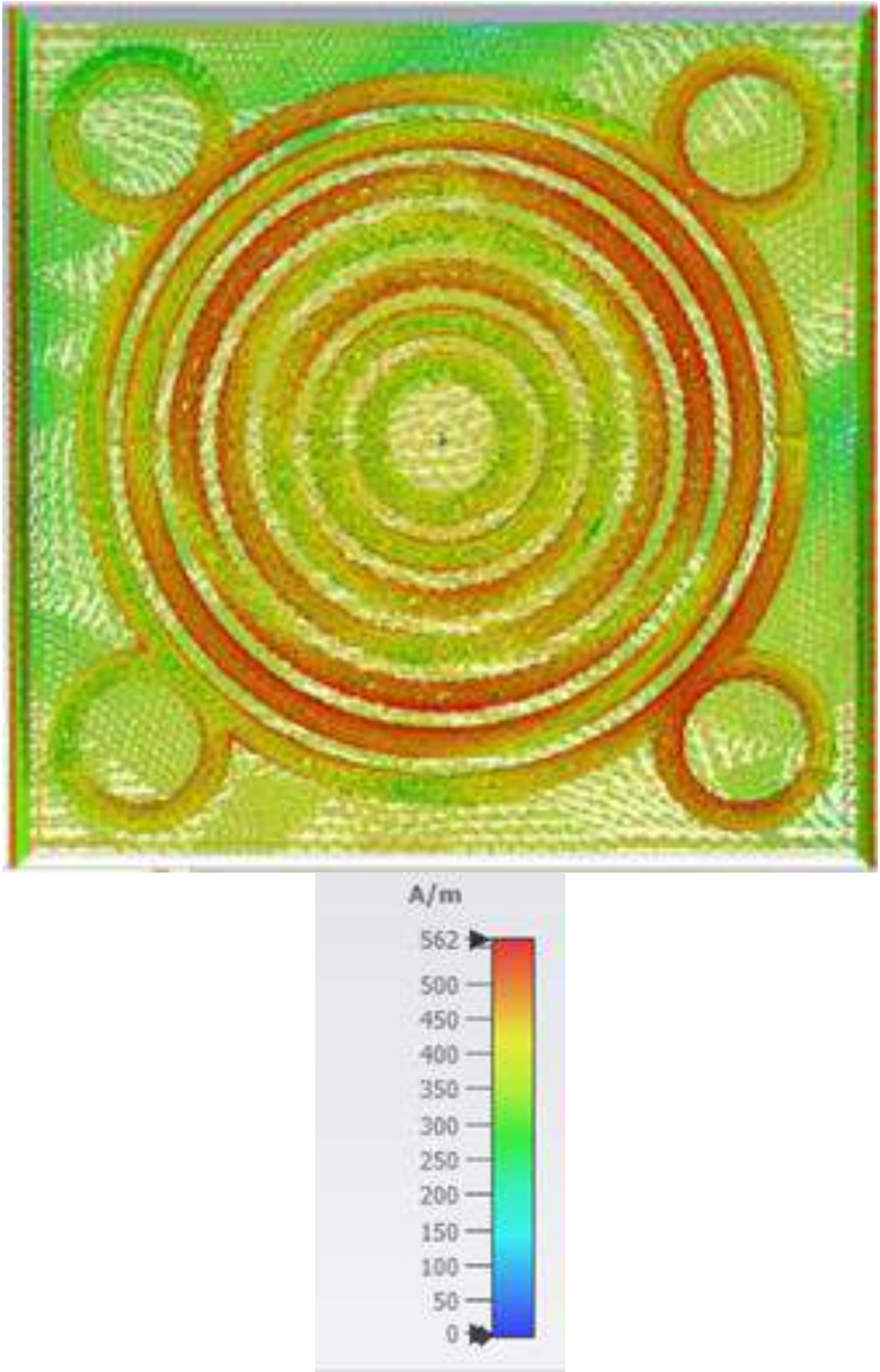
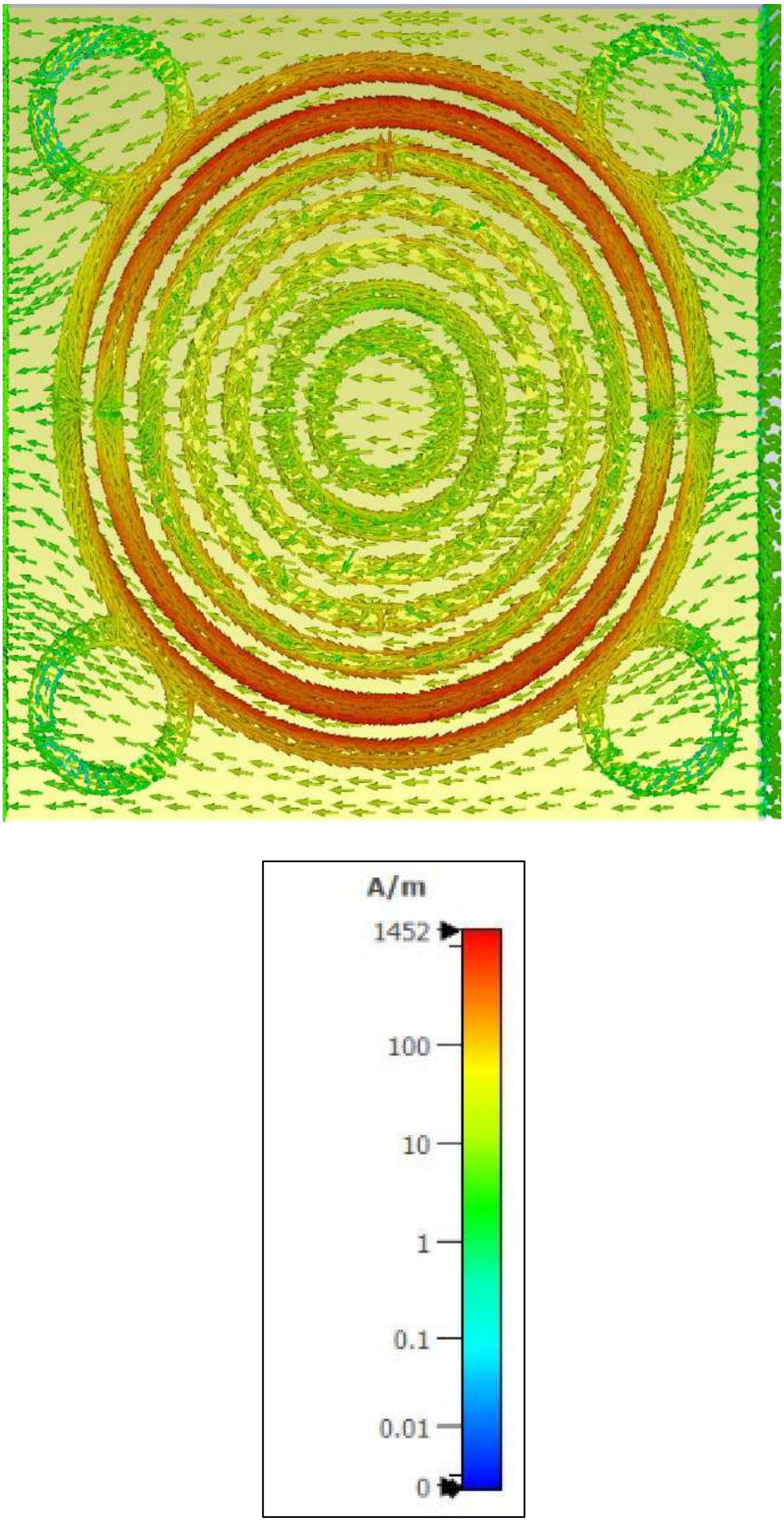
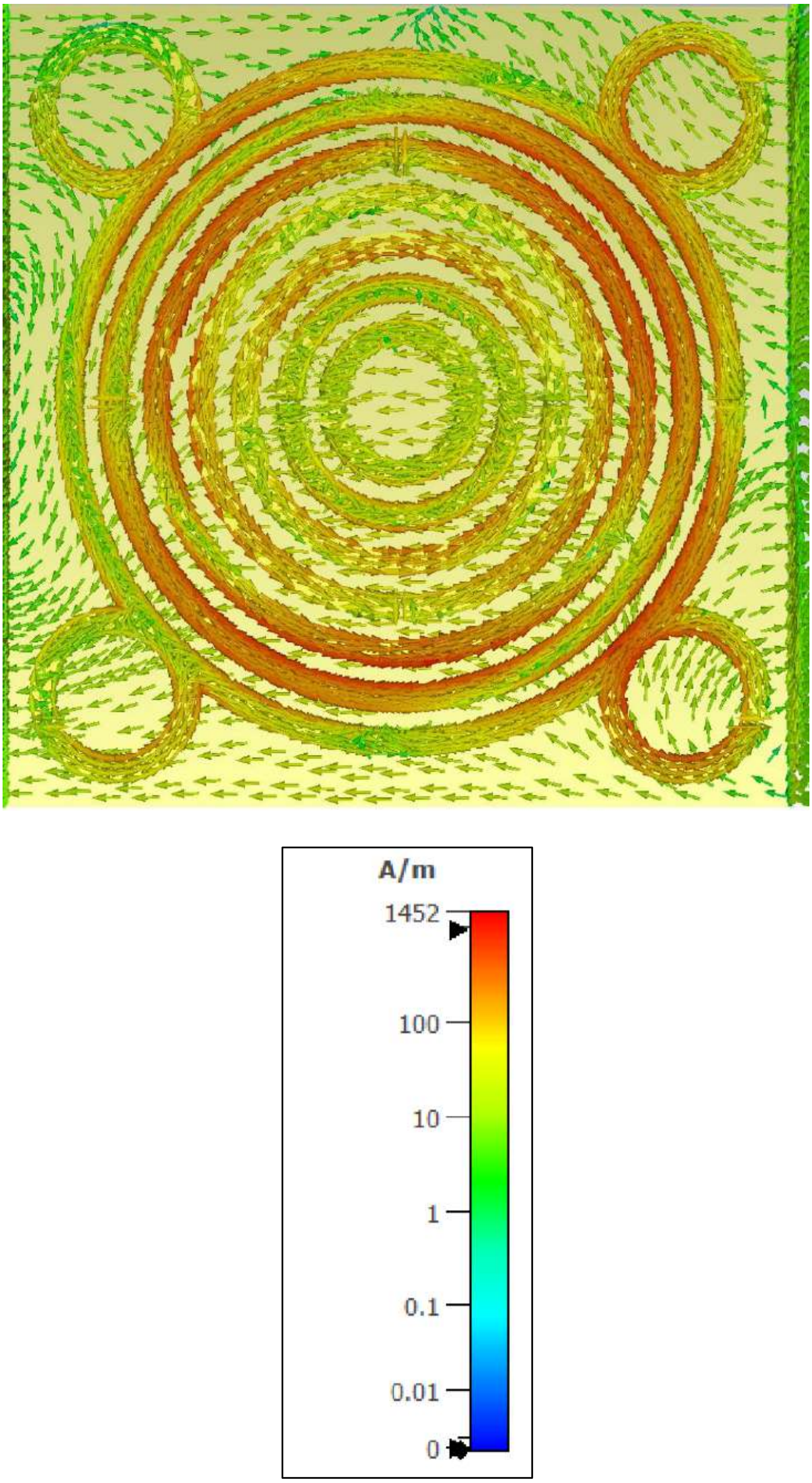


Figure 4.8 Surface Current



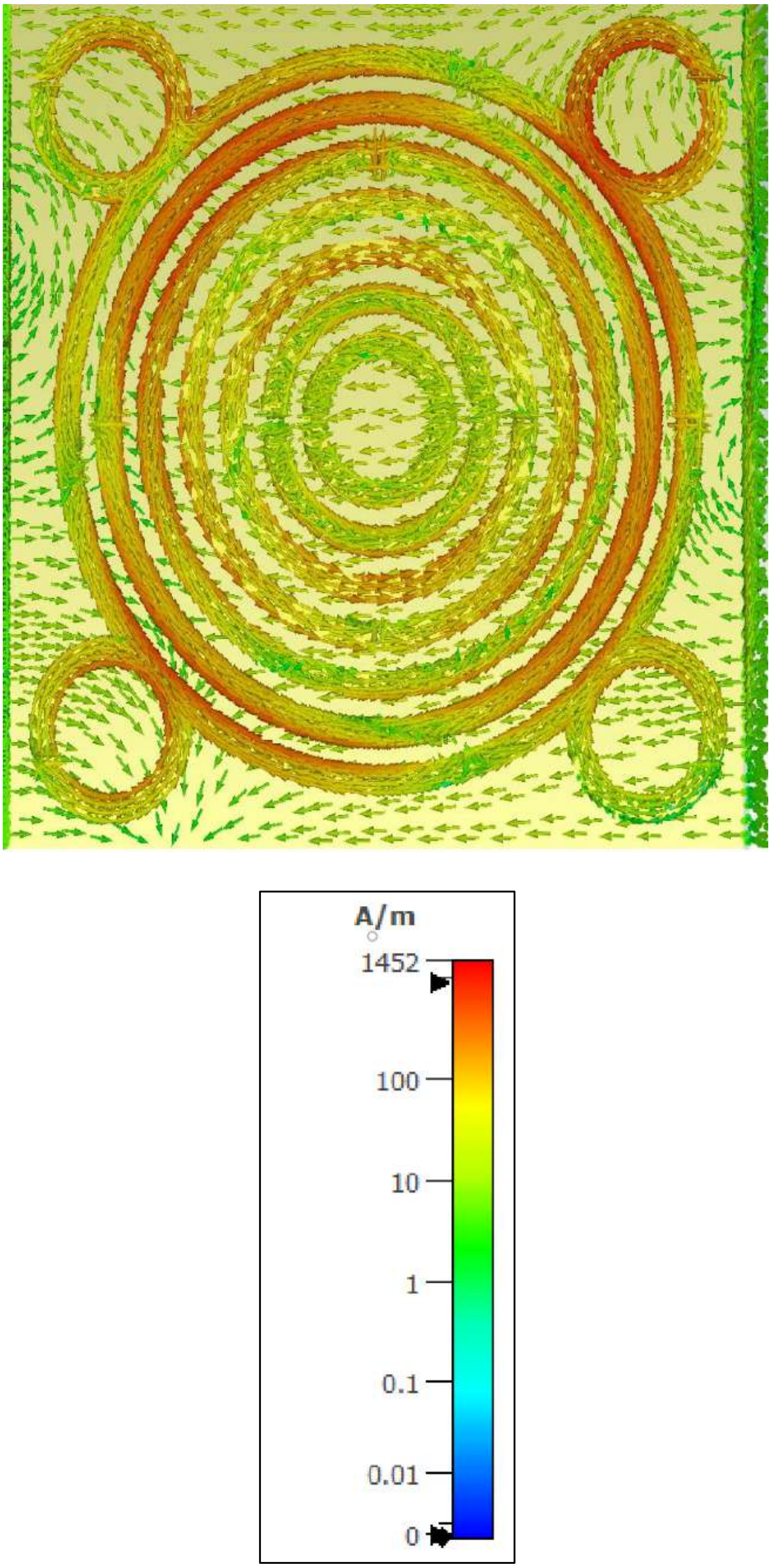
8

Figure 4.9 (8.903094 GHz)



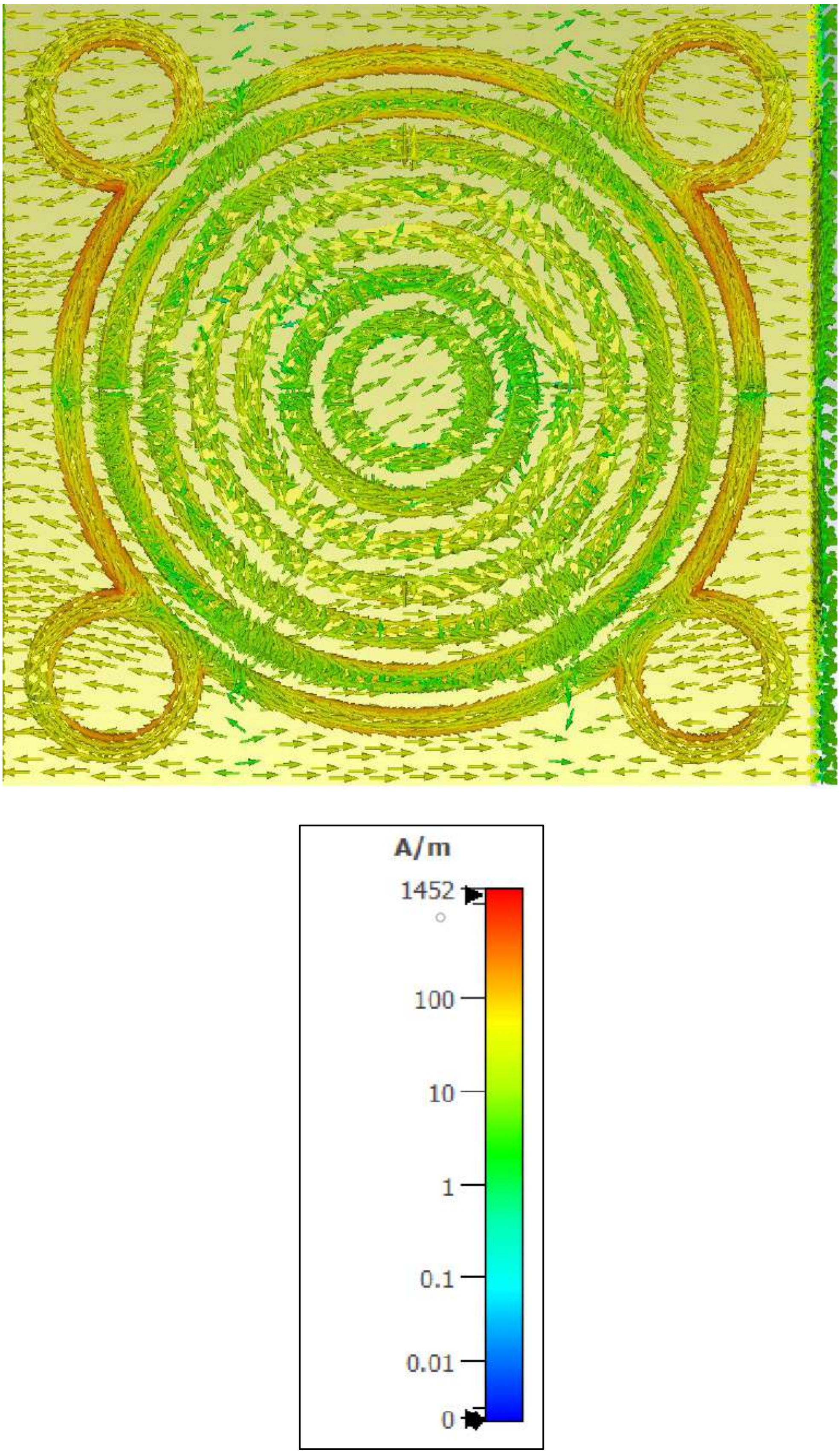
14

Figure 4.10 (14.102 GHz)



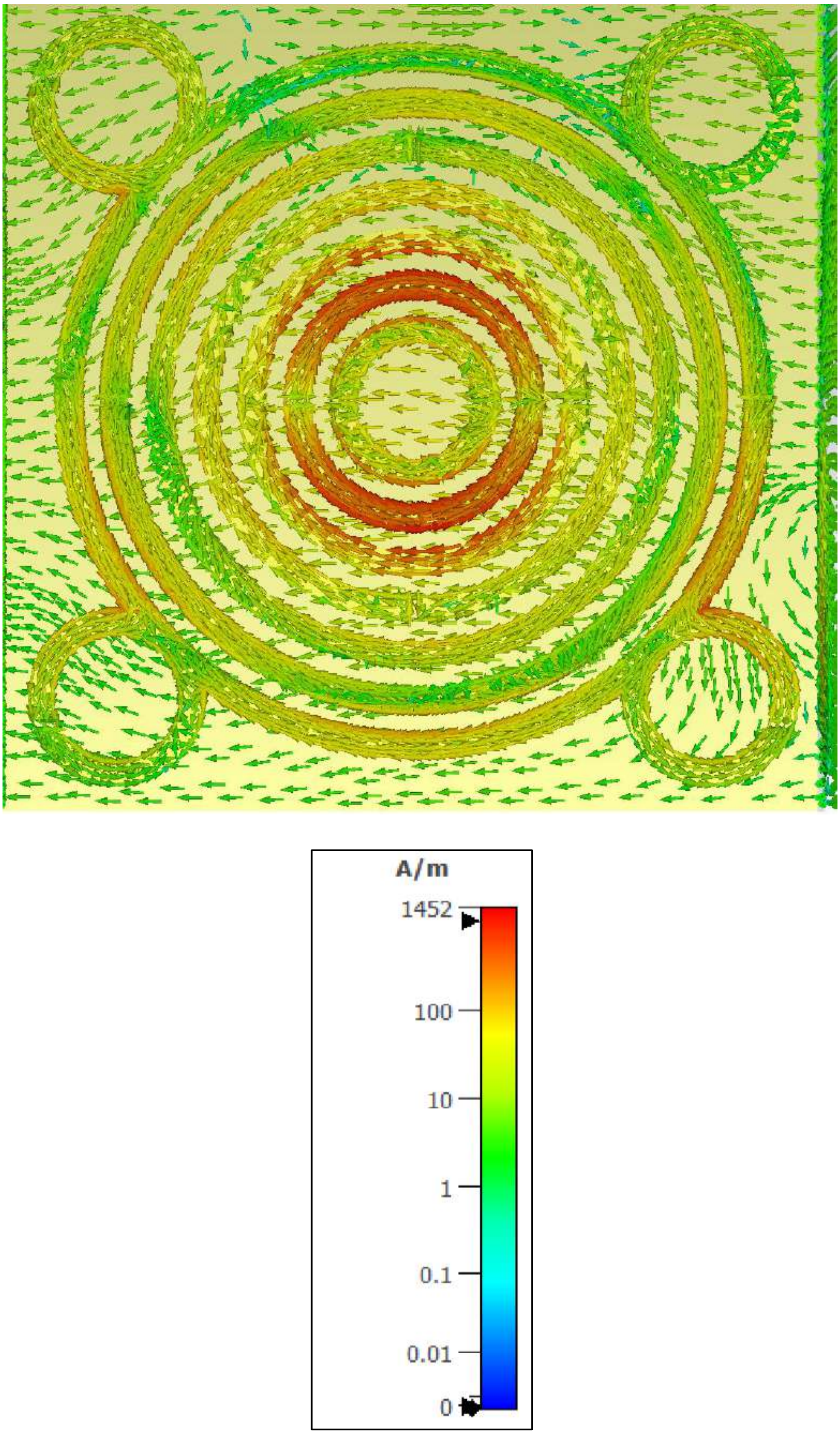
14.6

Figure 4.11 (14.606 GHz)



20.9

Figure 4.12 (20.996 GHz)



21

Figure 4.13 (21.68 GHz)

TABLE III. COMPARISON TABLE

Reference	**Publication Year**	**Resonance Frequency**	**Size Of Unit Cell**	**SNG or DNG**	**Substrate & Thickness**	**Maximum Polarization Angle Insensibility**	**Application**
[48]	2020	2.4 & 5.1	18 mm (0.14λ)	Not Mentioned	Double-Layered Rogers RO 3003 (1.75 mm)	90°	Higher frequencies, signal detection, radar imaging, satellite communications.
[46]	2022	5.376, 10.32 & 12.25	10 mm (0.179λ)	Not Mentioned	FR-4 (1.6mm)	60°	EM energy harvesting, SAR reduction for mobile devices, crowd-sensing/estimation application under WiFi coverage, WiFi signal sensing, EM coupling reduction in devices using both WiFi and LTE.
[49]	2021	4.5, 11.4	13.6mm	Not Mentioned	FR-4 (0.32mm)	90°	Not Mentioned
[14]	2021	6.16, 9.22, 11.6	11.5 mm	Not Mentioned	FR-4 (1.6 mm)	90°	Not Mentioned
Proposed	2023	8.903094, 14.102, 14.606, 20.996& 21.68	9 mm (0.12λ)	SNG	FR-4 (1.6mm)	180°	Radar technology, wireless power transfer, cloaking devices, antenna design, and electromagnetic wave manipulation.

CHAPTER 5

CONCLUSION

5.1 Introduction

The microwave frequency range metamaterial absorber (MMA) has been given as a fan grill-shaped circular split-ring-loaded metamaterial absorber. The absorptivity of the current MMA was determined to be 99.97%, 98.11%, 99.28%, 92.75%, and 95.28% at five distinct frequencies: 8.903094 GHz, 14.102 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz, respectively. Surface current distributions, magnetic fields, and electrical field patterns in MMA structures have been found at various frequencies, which explain the resonating behavior at different frequencies.

5.2 Output of the design

In this MMA design i designed a Fan grill shaped circular split-ring loaded metamaterial absorber for X,K & Ku band applications. I got five different types of absorption & five distinct frequencies respectively. In this design surface current, magnetic fields and electrical field are also available in this MMA design.

5.3 Conclusion

In this work, Fan grill shaped circular split-ring loaded metamaterial absorber for X,K & Ku band applications. The proposed structure has approximately ideal absorption at 8.903094 GHz, 14.102 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz manufactured and employed in hydrocarbon sensing, X, K & Ku band Applications. The energy harvesting uses of the suggested structure are also highlighted. Additional frequency bands might be added to the suggested structure for a variety of applications, such as wireless power transmission, radar communication, and antenna and waveguide manipulation design. The suggested absorber can be enhanced in the future and employed as a broad-band absorber in communication bands.

5.4 Prospective applications of the design

In this modern era metamaterial are uses in medical devices, optical filters, sensor detection infrastructure monitoring, lasers and smart solar power management etc. In my work X, K and Ku band applications are uses in many fields. They are Radar technology, wireless power transfer, cloaking devices, antenna design and electromagnetic wave manipulation.

5.5 Achievement

High absorption efficiency: At certain frequencies or within small frequency ranges, metamaterial absorbers have achieved high absorption efficiencies. Absorption efficiencies of more than 90% have been attained through rigorous design optimization. Permittivity and permeability values at various resonance frequencies (8.903094 GHz, 14.102 GHz, 14.606 GHz, 20.996 GHz, and 21.68 GHz). Permittivity is negative, while permeability is positive. As a result, we dubbed this absorber "single negative material" (SNG). Furthermore, at the required resonance frequency, the refractive index result is zero.

5.6 Future Work

Future applications for the suggested metamaterial absorber include radar, ships, smartphone apps, and more. It may be enhanced daily. These are but a few instances of the numerous avenues that metamaterial absorber development might go up. It is quite likely that the limitations now facing metamaterial absorbers will be significantly improved and new opportunities will arise if material science, manufacturing techniques, and electromagnetic analysis continue to evolve.

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