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Gas Stove Burner Shape with Inductive Tailed Rotational Symmetric Metamaterial Absorber for C and X Band Application

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DEDICATION

This thesis is a tribute to MY deserving parents and teachers.

CERTIFICATE OF APPROVAL

The Department of Electronic and Telecommunications Engineering (ETE) at International Islamic University Chittagong (IIUC) has accepted the thesis study of Apurba Ray Chowdhury (ID No. T191049) entitled " Gas Stove Burner Shape with Inductive Tailed Rotational Symmetric Metamaterial Absorber for C and X Band Application" as satisfactory in fulfillment of the requirements for the Degree of Bachelor in Electronic and Telecommunications Engineering and approved as to its style and contents for the examination held on th 2023.

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CANDIDATES DECLARATION

The written work that is presented in this thesis is not something that was submitted in the past for credit toward the completion of any other degrees or diplomas, nor does it contain any information that may be construed as violating any regulations that are now in effect.

Apurba Ray chowdhury

T-191049

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ABSTRACT

In this study, a multiband metamaterial (MM) absorber is shown. This absorber demonstrates the properties of the metamaterial at each resonance frequency. In the X band, absorption may be performed throughout the frequency spectrum between 10.373 and 10.825 gigahertz. At the frequencies of 4.12, 5.776, 10.472, and 10.696 GHz, where the maximum absorptions are respectively 99.4%, 99.9%, 95%, and 90.4%, four resonances gain in frequency in the C and X bands that have single negative (SNG) MM characteristics. These resonances occur at frequencies. In conclusion, compared with current work on MM, the highest angle sensitivity in Transverse Electromagnetic (TEM) mode, broadband absorption, and small size identify it as a more effective ideal absorber.

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List of Symbols

GHz	Giga Hertz
MM	Milimeter
ε	Relative Permittivity
μ	Relative Permeability
dB	Decibel
λ	Wavelength
Ω	Ohm
Z	Impedance
Γ	Reflection Coefficient
T	Transmission Coefficient

List of Abbreviation

MTM	Metamaterial
RF	Radio Frequency
MMA	Metamaterial Absorber
5G	Fifth Generation
SNG	Single Negative
DNG	Double Negative
CST	Computer Simulation Technology
ADS	Advanced Design System

Chapter 1

1.1 Introduction

1.1.1 Development of Metamaterial

Over the past decade, metamaterial ¹² has attracted a lot of attention in a specific industry because ³ of its useful properties, such as the ability to increase bandwidth, radiated power, directivity, and the ability to manipulate the flow of electromagnetic radiation. ³ Electromagnetic cloaking and negative index of refraction are just two of the many electromagnetic properties that cannot be found in nature but can be achieved by a new ³ class of materials that has been artificially created. Negative permittivity, permeability, and refractive index values are displayed by these substances. In addition, the structure of a metamaterial is what determines its characteristics, not the material itself. In addition, these materials are highly adaptable in terms of design, may have their properties altered, and can be tuned using different stimuli. Due to their appealing characteristics, metamaterials ⁵ have paved the way for the creation of novel devices and ideas and their potential use in a ⁵ wide variety of innovative applications. This means that metamaterials can be used ⁷ in a wide variety of fields and devices (biosensors, crowd control, absorbers, antennas, optical filters, infrastructure monitoring, intelligent solar power management, energy harvesters, and even shielding structures from earthquakes, etc.). An outlook on the difficulties and potential ⁷ of future metamaterial development is also provided[1].

The majority of inventors and regular people are familiar with the Popular term, which is left-handed materials (LHM). In 1968, ⁴ Veselago was the one who first conceived of using this material in this way. He asserts that it is theoretically conceivable for materials to possess both negative permeability and positive permittivity simultaneously. In 1999, the scientist John Pendry came up with a workable method for producing an LHM that did not ³ adhere to the right-hand rule in the same manner as the ordinary variety does. Smith presented new left-handed material in 2005 that displayed negative permeability and permittivity[2].

In addition to this, he did an experimental examination using a microwave to test its one-of-a-kind properties. Superior or beyond is the meaning of the word "metamaterial," which

originates from the Greek language. It is an artificially created synthetic composite material that is made by combining a number of components, such as metals and plastics. According to the definition provided by the European Union, a metamaterial is "an arrangement of manmade structural components, designed to achieve advantageous and unusual electromagnetic characteristics." In most cases, a metamaterial is used to improve the performance of an antenna system as well as its electromagnetic characteristics, absorb electromagnetic radiation, and to modify the material's elastic properties. In addition, the other applications of metamaterial in various industries include public safety, high-frequency battlefield communications, remote aerospace applications, sensor identification, and people who work in the field of the military as researchers also use the metamaterial to determine or detect the existence of explosives and contamination, among other things. In recent years, a number of academics have been focusing their attention on metamaterials in order to investigate the possibilities that they present in a variety of fields[3].

In 1968, Russian physicist Veselago was the first to propose the metamaterial history concept, which explains that it is theoretically feasible for a material to have negative permeability and permittivity values. 1999 was the year when John B. Pendry began his search for an alternative method of producing LHM that did not rely on the right-hand rule of a conventional typeface. A relation between the wave propagation vector and the pointing vector, which represents the wave propagation energy flow, is possessed by the LHM. However, in 2002, Lucent Technologies was the company that first introduced the new improvement in metamaterial for the construction of resonant antennas. As of 2005, it is being utilized to achieve peculiar electromagnetic features. In 2010, it was used for artificial media structure, and in 2017, the program enabled a metamaterial-based satellite antenna that is now commercially accessible. Both of these applications were made possible by the software[4].

On the other hand, as imaging technologies and nanofabrication continue to advance at a rapid pace, metamaterial structures have emerged as a significant focus of research. In addition to this, the number of research articles published in the field of metamaterials is also quickly expanding[5].

The qualities of the materials involved in a system are what define how it will react when electromagnetic fields are present. The benefits of materials can be summarised by establishing the macroscopic parameters known as permittivity and permeability. In addition, metamaterials can be separated into a number of distinct classes by virtue of the modified properties of the material in question. These include acoustic and transport, thermal, electromagnetic, and mechanical forces. From all this verse topic of metamaterial, metamaterial absorber is an individual field by which lots of benefits today's world can get and lots of problems may sort using metamaterial[6].

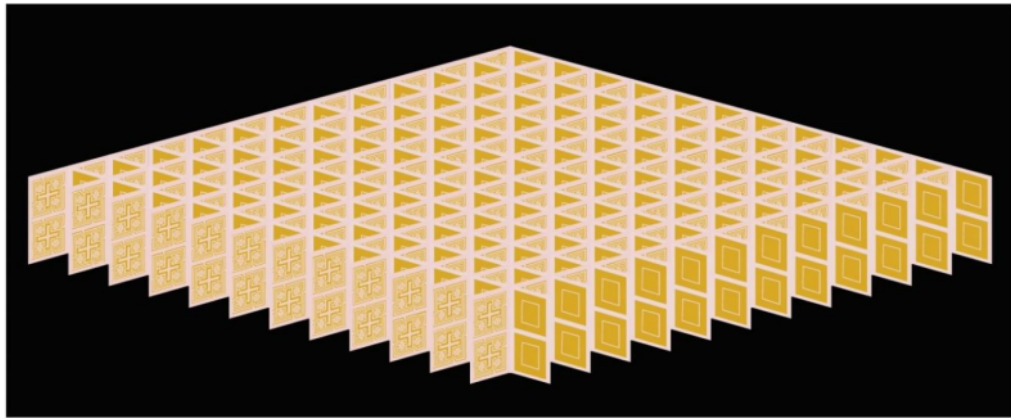


Figure 1. Metamaterial Absorber

1.1.2 Perfect Metamaterial Absorber

In 2008, Landy first claimed the design of a perfect metamaterial absorber in his review paper. Perfect MM are manmade designs that display negative permittivity, permeability, or both when EM waves pass through them. MM absorbers are one sort of artificially produced material that has some qualities that are not seen in natural substances. Though Landy claimed to design a perfect metamaterial absorber, there is some lacking in his design, like polarization sensitiveness. As a consequence of this, assembly is made more difficult as a result of the limitations imposed on the path that the incident wave must take in order to couple with the magnetic resonance[7].

1.1.3 Basic Characteristics

Talking about the characteristics of metamaterial, it has to show ¹⁵ the negative value of permittivity (ϵ) or permeability (μ) or both, ³¹ which became the factor to get the negative value of the refractive index ³¹ as we know that the refractive index is the ratio of the square root of permittivity and permeability. It has the capability to drive the incident electromagnetic wave in a particular direction or to harvest the electromagnetic wave to convert it for other applications. The characteristics it shows come out with a lot of engineering work that happens when the metamaterial is designed. The ratio of inductive and capacitive elements and their position has come into the factor to build the metamaterial absorber characteristics on the material[8].

1.2 Operating Field Depends ON

The operational field of a metamaterial absorber is contingent upon the features of the absorber itself, which are determined by the material for which it was created, the material's qualities, and the application that the absorber intends to carry out. Because metamaterial absorber is a relatively recent area of research in comparison to others, there are a great many operating domains already present in today's world where metamaterial absorber is making a significant difference and helping to be more advanced and more efficient in all directions. In the not-too-distant future, there will be an increase in the number of applications that are generated. The primary factors that have an effect on the working field of the metamaterial absorber[9].

1.2.1 Frequency Range

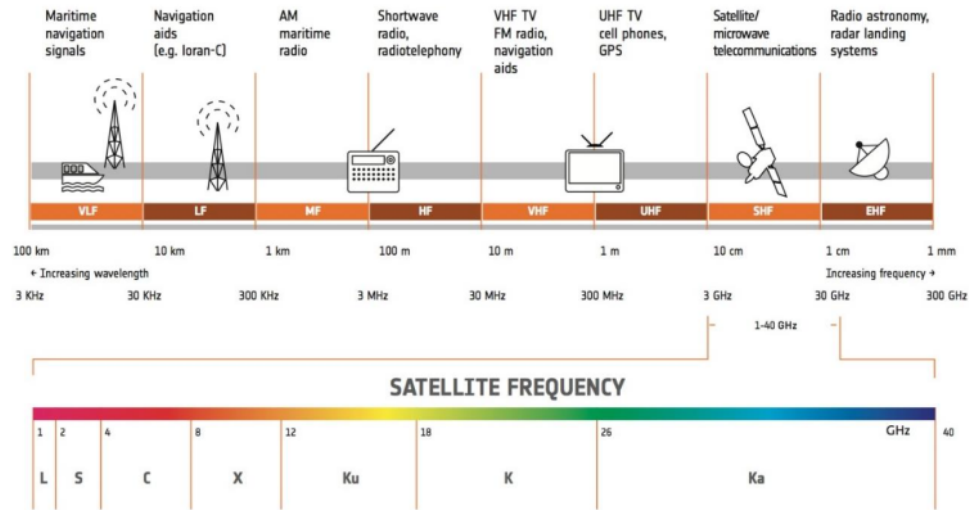


Figure 2. Satellite Frequency band

The structural design parameter and the metamaterial absorber optimize to get the frequency into the operating range. To understand the frequency range and specific applications in each frequency, various band (L, S, C, X, Ku, Ka) of frequency is declared, which are in the GHz range. As in recent times, maximum absorbers that are designed, working in that range of the frequency band, are helpful in identifying the application of absorbers in different operating fields[10].

- i. **L-band (1–2 GHz):** Carriers of the Global Positioning System (GPS) that are active in the L-band spectrum (1-2 GHz), such as Iridium and World Space; Inmarsat, which provides marine, terrestrial, and aerial communications; and satellite mobile phones.
- ii. **S-band (2–4 GHz):** The S-band is comprised of frequencies ranging from 2-4 GHz and is utilized by a variety of weather radars, ship radars, and communications satellites. Some satellites operated by NASA are able to communicate with both the International Space Station and the Space Shuttle. In May 2009, the European Commission awarded two separate 2x15 MHz portions of the S-band to Inmarsat and Solaris Mobile, which was a joint venture between Eutelsat and Astra at the time.

- iii. **C-band (4–8 GHz):** Its primary application is in the field of satellite communications, more specifically for the transmission of unprocessed satellite feeds and permanent satellite television networks. The fact that the C band is less susceptible to the effects of rain fades than the Ku band is one of the primary reasons for its widespread application in tropical regions. In 1962, a transponder on the very first Telstar satellite, which was functioning in this band, was responsible for transmitting the very first live transatlantic television broadcast.
- iv. **X-band (8–12 GHz):** Utilised most frequently by the military forces. Utilized in a wide variety of radar systems, including synthetic aperture radar, phased arrays, continuous-wave radar with or without pulses, and so on. X-band radar frequency sub-bands are utilized by a wide variety of civilian, military, and governmental organizations for a variety of tasks. Some of these tasks include monitoring the weather, controlling air traffic, managing marine vessel traffic, tracking defense, and determining the speed of vehicles for use in law enforcement operations.
- v. **Ku-band (12–18 GHz):** To communicate with one another via satellite. In Europe, the downlink frequency range used by direct broadcast satellite systems like Astra is located somewhere between 10.7 GHz and 12.75 GHz, and this is known as the Ku-band.
- vi. **Ka-band (26–40 GHz):** Communications satellites using the 27.5 GHz or 31 GHz uplink bands and military aircraft with high-resolution, short-range targeted radar.

1.2.2 Material Properties

The material features of the metamaterial have an effect on the operating field of the metamaterial. The operation of an electromagnetic wave absorber is determined not only by the type of material that is used but also by the electromagnetic properties of that material. These electromagnetic properties include the material's conductivity, permittivity, and permeability[11]. By utilizing a variety of materials, an operating field can be tuned to a specific frequency or even a range of frequencies to better suit the user's needs.

1.2.3 Bandwidth

The frequency range across which an electromagnetic wave absorber from a metamaterial functions at its highest level of efficiency is referred to as its bandwidth. While some metamaterial absorbers are designed for use throughout a more excellent frequency range, others are optimized for use across a more limited frequency range. Modifying the design parameters, such as the resonance characteristics of the metamaterial sections, may be essential in order to achieve the needed bandwidth. Modification of these design parameters may be necessary according to their application purpose[12].

1.2.4 Efficiency and Losses

The inherent losses that an absorber made of metamaterials has the potential to cause could have an effect on the operating field of the absorber. These losses may have been brought on by a wide range of factors, such as the conductivity of the material, dielectric losses, or defects in the structure. During the design phase, significant aspects that should be taken into account include limiting losses and increasing efficiency in order to permit optimal absorption within the desired working field. This is so that optimal absorption may be achieved[13].

1.2.5 Incident Angle

An absorber made of metamaterials may have an operating field that varies with angle. Absorbers can vary in their angular coverage, with some optimized for use at narrower angles of incidence than others. Specific incident angles or a range of curves can be targeted by adjusting the absorber's construction and design parameters to achieve the required absorption qualities.

1.2.6 Manufacturing Limitation

Absorbers designed are very small in size, both in dimension and thickness. So to design it in real life, advanced engineering machines are needed, which are very expensive and limited in the world. So free manufacturing is not possible. There is a possibility that a metamaterial absorber's operational field will be impacted by manufacturing restrictions.

The methods of construction, the availability of materials, and the limits imposed by practicality in the chosen manufacturing procedures may have an impact on both the design and performance of the absorber. In order to properly execute the desired operating field in practice, it is imperative that certain limits be taken into consideration.

1.2.7 Polarization

The features of metamaterials that are responsible for absorption can either be polarization-dependent or polarization-independent. It's likely that the polarization of the electromagnetic waves that are arriving will have an effect on the working field; this is something that could happen. Incorporating unique design considerations into a system allows for the possibility of accomplishing a number of distinct objectives, including the generation of polarization-insensitive absorption and the targeting of specific polarization states[14].

1.3 Application Field

There are a lot of applications already implemented in today's technology that use metamaterial absorbers to update their working efficiency and minimize their cost. Some major applications are EM Energy Harvesting, Electromagnetic Interference Suppression, Solar energy conversion Terahertz Imaging, Aerospace, and Stealth Technology, Crowd Sensing, Radar Cross-Section Reduction, Specific Absorption Rate Reduction, Refractive Index Sensing, Satellite Application, Antenna Gain and Directivity Enhancement, Sensing Applications, noise reduction etc. Here in this chapter, we are going to discuss general things about some of the applications.

1.3.1 Crowd Sensing



Figure 3. Interconnection with users

Nowadays, people are using so many services that depend on the cloud system, or you can say cloud computing, which makes the lives of people much more effortless than in the past. Whenever we search for anything on the internet using a laptop, mobile, or other device, this device shows the relevant result that we are exploring. So, the devices always hear what we are talking about, understand what we are searching for, and accordingly show the results we are looking for. Even in Fig.3, we can see some of them are talking, some of them are browsing, and doing many things which are part of the communication System. All of this which they are doing is possible if they are connected to a high-speed data service like 5G or Sub 6G. This is possible if the 5G transmitter can connect all the devices efficiently, which is impossible by conventional antenna systems unless we are using any device like a metamaterial absorber that can direct the beam towards the receiver[15].

1.3.2 Stealth Technology

In developing this kind of technology, metamaterial plays a critical role in the implementation. Here metamaterial absorber works like a focusing lens and also trap

electromagnetic wave and produce electricity. The size of the metamaterial absorber array can be different in size according to its applications. Like US Army already uses stealth aircraft, which no radar can detect Fig.4. The aircraft uses metamaterial just under the wings where the fuel tank is present, and its size is much bigger, which looks like we use solar panels in huge numbers. At the time, they used metamaterial to produce electricity and trap electromagnetic waves in that position. ⁶ The size of the array is made according to the size of the wing, which means it depends on the transmitter from where the electromagnetic wave is coming. The distance between the transmitter aperture and the near field from where we have to calculate the range of the cross element. It gives the minimum value of skin depth. Calculating this skin depth, we have to construct the structure of the metamaterial. Some modern trains are using this technology already.



Figure 4. Stealth Aircraft

1.3.3 Antenna Gain & Directivity Enhancement

Lots of antennae are designed, which are unable to be implemented because of some issues that harm the situation. More of the devices we are using are still not capable of SAR reduction. Also, the World Health Organization is not giving the pass to use. As we know, 5G is still not able to be set for this kind of problem. A broadband antenna is targeted to operate at 3.5GHz. They also operate something higher and lower also. This characteristic affects other devices which operate close to 3.5GHz. The altimeter in aircraft uses radar to

detect the height of the ground at the time of landing. The radar sends an electromagnetic wave into the ground, which reflects and comes back to the



Figure 5. Unwanted Radiation

radar by which height is detected. The operating frequency of this is somewhere around (3.4 – 4.2)GHz. So if there is a tower operating in that range, this might pass wrong information to the altimeter of the aircraft, and there is a chance of an accident because of that. That's why a lot of first-world countries refuse to use this 5G antenna. So there is a chance of using a metamaterial absorber that can absorb 3.5GHz co-polarized part and can detect cross-polarization that is different other than that absorber take as reflected electromagnetic wave of the radar transmitted[16].

1.3.4 Radar Cross-Section Reduction



Figure 6. Radar Array

Radar is one kind of directive antenna that is made of lots of array antennae and goes in a particular direction. If the radar is connected to the nose of the aircraft, not big enough ground radar can't detect the plane as there was no phased array antenna present in the past. They are using a metamaterial phase array antenna produced, which reduces the cross-section reduction and also reduces the size of the radar. In the past nose of aircraft was significant as the size of the radar was big, and lots of devices need to set the nose of the plane in the center of mass lots of fuel was invested because of that, but it is not a problem nowadays, which reduce the cost and size of the nose of aircraft[17].

1.3.5 Energy Harvesting

It's the process of converting electromagnetic energy into electric energy. In this process, we can trap electromagnetic waves and use this energy to charge devices like smartwatches. In this method, the watch can be automatically rechargeable. In this process, the watch is self-capable to recharge itself. So we can set a device in the watch which traps

the surrounding electromagnetic wave and take the required energy from that to charge the battery. That way, it can be self-smart[18].



Figure 7. Smart Watch

1.4 Design and Drawing Tools

To design a metamaterial absorber, the most recognized software is the Computer Simulation Technology (CST) Studio Suite. Here, we use the CST Studio Suite 2020 version to design the absorber. To show the metamaterial characteristics, lots of graphs need to be drawn. For that, we use Origin Pro 9.0.

Dassault Systèmes Simulia developed CST Studio Suite, initially released in 1998 as the name CST Microwave Studio and later in 2005 renamed CST Studio Suite. It's a multipurpose software that not only design metamaterial absorber but also design antenna, circuit, and PCB. Further we wil discuss in chapter3.

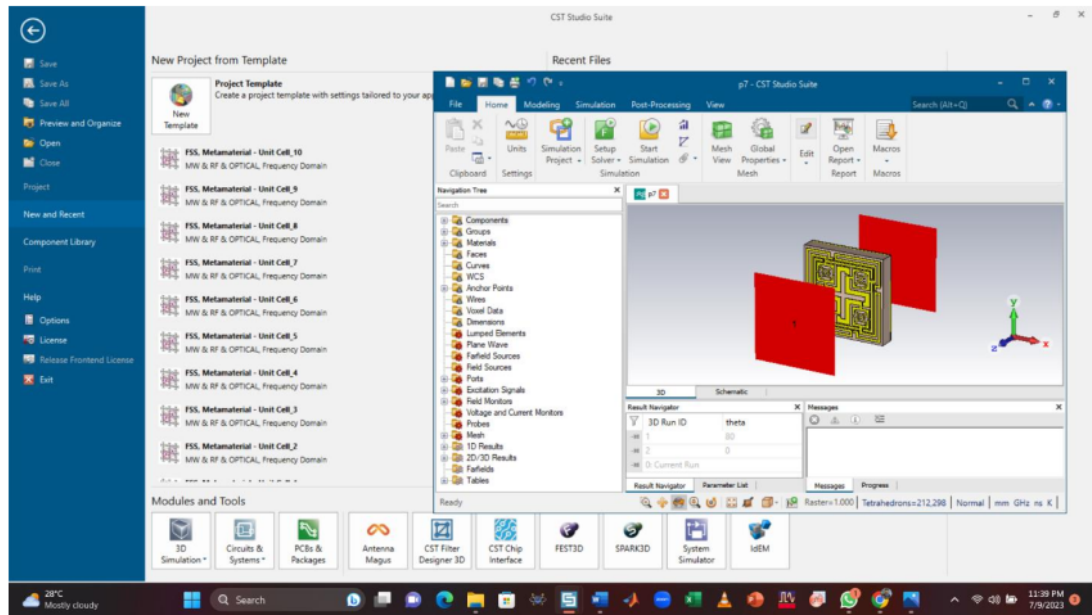


Figure 8. CST Working Plain

1.5 Motivation

I didn't directly choose Metamaterial absorbers as my research topic. From an early age, I have been very interested in updated generation planes, Chopper, fighting Jets, etc. In searching for new generation fighting jets, Choppers, and aircraft, I saw some updated generation fighting aircraft that are used by the American Army and can't be detected by radar. By knowing it, I became very much interested to know the reason behind it. After reading so many articles, I understand that metamaterial is used to make this fighting aircraft. I became curious about metamaterial, what it is, how it works, how its functionalities it, and how to design a metamaterial absorber. Then, I am reading some research papers on Metamaterial absorbers and developing metamaterial absorbers for various applications. As I am in my last year of graduation, I must complete my thesis. I chose the metamaterial absorber as my research topic.

The most important motivation is these two point below

- Many metamaterial(MM) absorbers proposed till date show some discrete MM properties, but none of them has shown perfect polarization insensitivity in terms

of co and cross-polarization, so there is a scope to design an ideal MM absorber for both co and cross-polarization incident wave

- It is hard to find an MM absorber that has shown wideband absorption without lumped elements, so I am motivated to design a uniquely shaped MM that will show broadband absorption at C & X bands along with MM properties that can be proposed for some potential application

But before confirming selecting the metamaterial absorber as my research topic, I had to ensure that someone in our department knew about metamaterial absorbers and did research on metamaterial absorbers. Three months before starting my thesis work, luckily, a senior assistant professor of our department came from Malaysia after completing his Ph.D. Luckily His main topic of research is related to metamaterial absorbers.

1.6 Essence

It is necessary for conventional absorbers, such as those made of conductive materials, to have a thickness that is in the same order as the wavelength that they intend to absorb. The profile of a metamaterial absorber can be substantially thinner, generally being less than a fourth of the wavelength that is coming in, and still achieve a high level of absorption.

2.1 Literature Review

17

A review of literature critically evaluates and summarizes previously published studies and academic works on a certain subject or research issue. It entails reviewing and assessing the body of knowledge that is already accessible, outlining significant discoveries, locating gaps or disagreements, and setting the context of your study.

An extensive survey of the state of understanding of a given issue is what a review of the literature is intended to do. Understanding what has previously been investigated, what ideas or concepts are in use, and what knowledge gaps still need to be filled aids researchers in their work. A literature review also enables researchers to locate their work in relation to the corpus of prior research, identify methodology or methods that have been employed in the past, and provide a solid theoretical foundation for their investigation.

Typically, a literature review includes the following elements:

- i. **Introduction:** By presenting the study question or topic in detail, the introduction prepares the reader for the literature review. It discusses the importance and continuing relevance of the selected topic and outlines the reasons why it is crucial to learn about and comprehend the current body of research in this field.
- ii. **Search Strategy:** Finding pertinent books is discussed in this section. Scholarly books, articles from conferences, thesis, and other publications can be found by researchers via academic search engines, libraries, and internet resources. The search strategy contains a description of the databases and search keywords utilised, together with any excluded or included criteria that may have been employed.
- iii. **Selection and Evaluation:** The criteria that were utilised to choose the resources that were inserted in the literature review are discussed below by the researchers. The criteria might include things like how well the source fits the research topic, when it was published, how well the study was designed, and how well-known and reputable the source is. The review process' assessment step makes sure that the sources used are trustworthy and offer insightful information.

- iv. **Summary and Synthesis:** The key results, justifications, and techniques of the chosen sources are summarized in this section. The essential contributions of each source are highlighted in a separate summary of each source. When prevalent themes, trends, or patterns are found among the authorities, synthesis takes place. This procedure aids scientists in getting a broad picture of the body of already accepted knowledge and locating the key areas of agreement or dispute.
- v. **Critique and Analysis:** Researchers critically evaluate the advantages and disadvantages of the prior study in this section. They assess the methodologies of examination used, sample sizes, data processing strategies, and any biases or constraints. The objective is to determine the caliber of the study, as well as its significance and applicability to the question being investigated.
- vi. **Conceptual Framework:** An important element of a literature review is the conceptual framework. Creating a framework that incorporates the main ideas, theories, and models noted in the review is required. Through the lens of this framework, the researcher is able to analyze and evaluate their own results as well as lay the theoretical groundwork for the study.
- vii. **Conclusion:** A literature review's conclusion aims to highlight the main conclusions and important takeaways from the review process. It restates the research topic and emphasizes how important the study is to resolve any gaps in knowledge or unsolved problems that have been highlighted in the literature. The conclusion also serves as a bridge between the remaining parts of the thesis or research paper.

By observing these guidelines, a literature review offers a thorough study of the available research, synthesizes the findings and concepts, evaluates their merits and shortcomings, and creates a conceptual foundation for further research. It is essential for laying a solid basis for the researcher's own work and displaying their knowledge of the larger academic discussion within their topic[19].

2.2 Previous Work Review

¹⁶ Due to its potential use in both civil and military applications, including sensor polarization control, ¹⁶ specific absorption rate (SAR) reduction, and stealth technology, electromagnetic absorbers have drawn the attention of numerous academics over the past several decades.

2.3 Performance Analysis

The design of metamaterial absorbers has been optimized in a number of books and published articles. In order to get the appropriate absorption qualities, this involves experimenting with different geometries, including resonant structures, frequency-selective surfaces (FSS), and gradient-index materials. To improve the absorber's performance, the work frequently uses theoretical analysis, simulations, and optimization approaches. In the study of metamaterial absorbers, achieving broadband absorption is a typical goal. A wide variety of frequencies can be absorbed thanks to the designs and structures that have been suggested in several publications. To increase the bandwidth of the absorber, these efforts frequently focus on optimizing geometrical factors, material characteristics, and resonant structures. Another crucial element of metamaterial absorber design is achieving high absorption effectiveness. The goal of several studies and books has been to enhance the absorber's capacity to collect and transform incident electromagnetic waves into heat or other useful types of energy. In order to maximize absorption effectiveness, strategies including impedance matching, multiple resonances, and polarization selectivity have been investigated. Metamaterial absorbers can now perform functions beyond simple absorption, according to several published research. In these studies, tunable absorbers with features like frequency tunability or polarization selectivity are investigated. Metamaterial absorbers with other features, such as wavefront modification, sensing abilities, or interaction with other devices, have been the subject of various investigations. A common topic in publications on metamaterial absorbers is how to fabricate them for real-world applications. These articles describe numerous fabrication processes, including lithography, nanoimprint lithography, additive manufacturing, and etching procedures. To create metamaterial absorbers with excellent performance, the emphasis is on building scalable, affordable, and trustworthy manufacturing procedures.

Experiments that validate the results of metamaterial absorbers are frequently included in articles and books. Creating prototypes and taking measurements are commonly included in these projects in order to assess how well practical findings match theoretical forecasts. The recommended designs are supported by experimental validation, which offers concrete proof of the absorber's effectiveness. Metamaterial absorbers are being studied for use in a variety of systems, such as communication, energy harvesting, energy harvesting technology, sensing, imaging, and stealth technology. Publications often emphasize the benefits, difficulties, and possibilities for practical uses of metamaterial absorbers within various disciplines and speculate on their possible influence.

You should be aware that there is constantly fresh research being published on the subject of metamaterial absorbers. It is suggested to consult current scientific databases, specialized journals, and proceedings from conferences that concentrate on electromagnetic metamaterials as well as associated fields to gain a more thorough and up-to-date knowledge concerning the performance and particular works associated with metamaterial absorbers.

2.3.1 Journal Paper Selection Strategy for Literature Review

The process of selecting journal articles for a literature review is one of the most significant procedures involved in conducting research. Your goal should be to locate and include papers that are important to your research topic, are of high quality, and offer substantial insights into the subject matter you are investigating. You will find that the following procedure is helpful in selecting the right journal articles for your literature review:

1. **Please be as specific as possible regarding the nature of your inquiry:** Before you begin your search for publications, you should be certain that you have a well-defined research topic or aim in mind for your literature review. Your search will be more focused as a result, and it will be simpler for you to locate items that are important to your inquiry.
2. **Establish criteria for who should be included and who should be excluded:** Create specific criteria to determine which papers will be included and which will not be included. Criteria could include the type of study (for example, a theoretical

review or empirical research), the publication date, and the study's relevance to the problem that you are researching.

3. **Choose the Appropriate Databases for Your Needs:** In order to conduct a successful literature search, you should make use of the appropriate academic databases and search engines. A few popular ones include academic libraries, Google Scholar, IEEE Xplore, and PubMed.
4. **Get started with your preliminary lookup right away:** You should begin your search by selecting general terms and phrases connected to the topic you are studying. This will make it possible for you to uncover a large pool of documents that may or may not be relevant to your search.
5. **Examine the results of your research, which are as follows:** Examine the titles and abstracts of the papers that come up in the search results with the purpose of discovering whether or not any of them are pertinent to the subject of your research. At this point, you should exclude a document from consideration if you determine that it does not meet the inclusion criteria you've established.
6. **Comprehensive Analysis of the Text:** Obtain the full texts of the selected papers, and go through each one of them reading it from beginning to end. Evaluate the methodology, findings, and discussion in terms of how well they apply to the research problem that you are attempting to solve.
7. **The Monitoring of Citations:** Take the time to read the citations that are included in the papers that you are evaluating. It is in your best interest to investigate any references that appear to be relevant to the problem you are trying to solve, as doing so will likely lead you to other sources that are worth your time.
8. **Examine the Level of Quality of the Papers:** Consider the overall quality of each piece of writing. Think about things like the credibility of the publication, the credentials of the author, the precision of the research methodology, and the significance of the findings.
9. **Organization of Paper Based on Classification:** Arrange the selected papers in categories or subjects that correspond to the numerous features of the study question you are investigating. By using this method, you will be able to generate a structured review and identify any holes in the existing body of research.

10. **Make sure to keep accurate records:** Keep detailed records of the articles that you have read, including summaries, bibliographies, and notes on how the articles relate to your research.
11. **In conclusion, the following were the findings:** Compose a literature review that offers a synopsis of the most significant findings and revelations to emerge from the studies that you have selected. Discuss both the positive and negative implications of the research.
12. **Regularly revise your analysis to account for new information:** The reviews of the relevant literature are always evolving, particularly because new research is being published on a regular basis. Make it a practice to update your review on a regular basis, particularly if your study takes place over a prolonged period of time, because this will ensure that you don't miss any important details.
13. **To collect people's responses:** Before you hand in your literature review, it is a good idea to solicit feedback from your coworkers, mentors, or advisers to ensure that it is exhaustive and well-organized, that you haven't missed any significant studies, and that you haven't missed any important studies.

A literature review should not just list and summarize studies; rather, it should critically evaluate and synthesize the available research ²⁷ in order to provide a thorough understanding of the current state of knowledge on the problem that your study is investigating.

2.3.2 Recent Paper Analysis

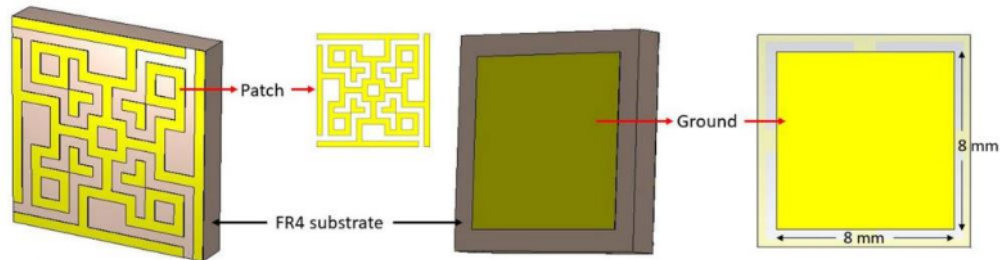


Figure 9. Absorber

Here in Fig.9, a symmetrically shaped incident angle independent metamaterial designed for X and Ku bands is designed by Dr. Saif Hannan, where four resonance frequencies are obtained, which show maximum absorption over 99%. Also, its polarization angle

insensitivity is up to 90° . Here, they use ¹FR-4 as substrate and copper annealed as ground and patch. They used a defective ground, which helped to tune the frequency. The absorber get some rare result and have an uncommon shape, which makes this an impactful research in the field of metamaterial[12]. Though lots of design we see is similar in look, the ratio of inductive and capacitive are not the same, and the absorption quality resonance frequency is also different. Because of that, their field of application is also different.

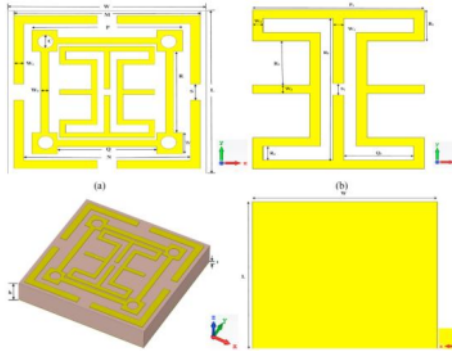


Figure 10. Absorber

An asymmetrical E-shaped absorber is designed for stealth application and EMI shielding by Md Bellal Hossain, where triple band frequency has been absorbed with over 99% absorption rate. They also analyze the resonance frequency with ADS circuit simulation. $0.179\lambda \times 0.179\lambda$ dimensioned shaped metamaterial absorber has been designed where λ is the wavelength for the minimum resonance frequency they get for the absorber they designed. They simulate the ¹⁸absorber for both transverse electric (TE) and transverse magnetic (TM) modes where the maximum incident angle insensitivity is over 60° [20].

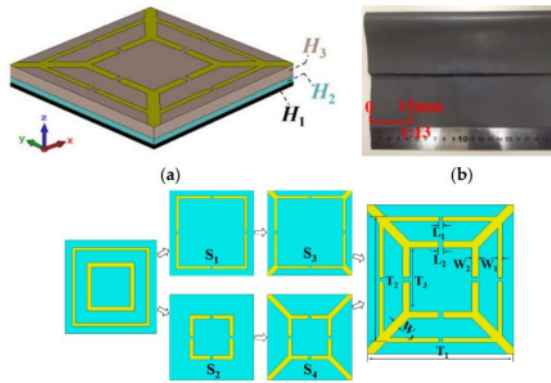


Figure 11. Absorber

A L, S, C, X, and Ku band absorber is designed to operate for magnetic rubber and a lot of applications down there where it can successfully operate. At 1.7GHz, 3.87GHz, 5.96GHz, 9.4–10.4 GHz, and 14 GHz, the absorption is over 90%, where carbon is used as a doping amount. The copper they use in the absorber works as an inductor, and the open space in the patch works as a capacitor.

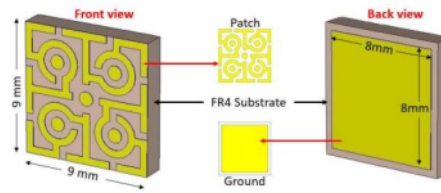


FIGURE 1. The designed unit cell.

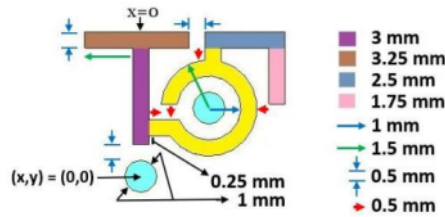


Figure 12. Absorber

A split ring metamaterial absorber designed by Dr. Saif Hannan for triple band application where the absorber shows SNG and DNG, both kinds of values. For patch and ground, copper had been used, and for dielectric substrate, FR-4 was used. Average absorption is over 95% here. To create resonance, we can see a split ring creates a coupling where

electromagnetic waves create a dipole characteristic. The absorber is applied in X, Ku & K band applications[21].

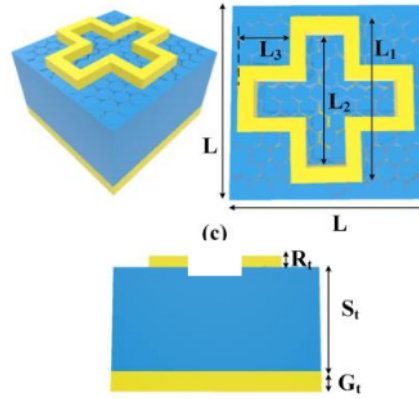


Figure 13. Absorber

A cutting-edge development in electromagnetic wave absorption technology is a metamaterial absorber with a characteristic plus-shaped structure, a completely linked ground plane and an enclosed copper patch, separated by a dielectric substrate. The fundamental function of this metamaterial absorber is to effectively absorb electromagnetic radiation across a broad frequency range by taking use of the special characteristics of metamaterials. A painstakingly made copper patch in the form of a plus sign (+) serves as the absorber's main component. In order to obtain remarkable absorption qualities across a wide frequency range, this geometrical arrangement has been tuned. The copper substance works well as a conductor to capture electromagnetic energy[22].

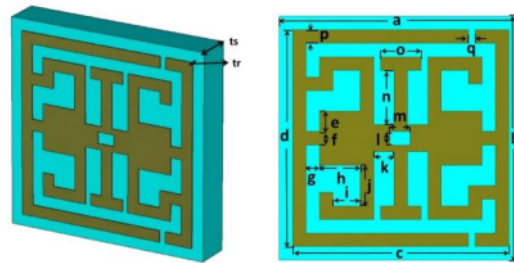


Figure 14. Absorber

0.118 inches on a side metamaterial absorber with five resonance frequencies and polarizations, and insensitivity to incidence angles of up to 90 and 60 degrees. Dimensions: 0.118 inches on a side. The excellent effective medium ratio of 8.47 was attained by this

endeavor. The capability of modifying the features and thickness of the dielectric substrate in order to tailor the absorber's absorption capabilities to certain frequency bands or applications enables designers to be more flexible in their approach to the design process.

2.4 Summary

To learn more about and enhance their capacities to absorb and manipulate electromagnetic waves, scientists carry out research on metamaterial absorbers. The main objective is to create materials with effective frequency absorption. To improve the functionality and performance of these absorbers, they investigate various manufacturing methods and factors. The ultimate goal is to use metamaterial absorbers in a variety of domains, such as electromagnetic interference reduction, energy harvesting, communications, sensing, and stealth technologies.

2.5 Objective

Through reading a large number of papers, I was able to identify a few issues that are now being worked on by the development team to get the application a couple of steps closer to completion. In a similar vein, I wish to find a solution to the issue of electromagnetic incidence angle sensitivity. The design of the patch has to be symmetric at various electromagnetic incidence angles so that the metamaterial absorber won't be affected by the incident angle of the electromagnetic radiation. The incident wave was reflected off of the same sort of surface as before, and it behaved in the same way as before regardless of the angle. It is difficult to obtain broadband absorption without the use of a lumped element, which is despite the fact that getting broadband absorption on a metamaterial absorber is an essential goal that every designer of a metamaterial absorber strives to accomplish. Because of this, many absorbers have lumped components on the patch of the design in order to achieve broadband absorption, which makes it more difficult to apply the absorber at the appropriate location. The maximal absorber that was developed and simulated demonstrates distinct metamaterial features that need to be corrected. Another target is to make the absorber polarization insensitive, both in the co-polarization and cross-polarization directions.

2.6 Parameter Selection

Selecting the parameter is one of the most important things that may affect the result and also the application field. The choice of parameters has a significant influence on the functioning and performance of a metamaterial absorber, making it essential when developing one. Metamaterial absorbers are constructed devices with the purpose of efficiently absorbing electromagnetic waves, usually in a specified frequency range. The absorption features of a metamaterial absorber, such as the absorption bandwidth, absorption peak frequency, and polarization sensitivity, are determined by the design parameters used.

The absorption efficiency is greatly influenced by the parameters used, such as the dimensions, form, and arrangement of metamaterial unit cells. A high absorption efficiency may be achieved by carefully choosing the parameters to maximize the absorption of incoming electromagnetic waves under the required frequency range.

The metamaterial absorber's bandwidth and frequency selectivity are influenced by the parameter selection. It is possible to construct absorbers with a broad bandwidth or narrowband absorption by choosing the proper parameters based on the needs of the particular application.

Both polarization-sensitive and polarization-insensitive metamaterial absorbers are possible to create. The choice of parameters, such as the form and position of the metamaterial unit cells, affects how the absorber reacts to various incident wave polarizations. With careful parameter selection, it is possible to construct absorbers that are either polarization insensitive for applications where polarization filtering is not necessary or polarization sensitive for those.

The limitations imposed by fabrication and manufacturing methods should be taken into account while choosing parameters. When selecting parameters for the metamaterial absorber design, it is important to take into account realistic and useful restrictions, such as the resolution of the production technique or material accessibility.

According to the change of parameters, the number of the capacitive and inductive elements also changes, which affects the resonance frequency, the peak of resonance frequency, the position of resonance frequency, and many things.

So by studying all these things, I understand that the ratio of the capacitive and inductive elements has to be in the mathematically correct manner. For that, the dimension of the patch needs to change accordingly[23].

2.7 Material Selection

The choice of material is an important consideration when building a metamaterial absorber since it has a direct impact on the electromagnetic characteristics and overall effectiveness of the absorber.

The material selection affects the electromagnetic characteristics of the metamaterial absorber, including complex permittivity and permeability. These characteristics, which include those of absorption, reflection, and transmission, determine how the substance interacts with electromagnetic waves. It is feasible to maximize the absorption performance within the intended frequency range by choosing suitable materials with specialized electromagnetic characteristics.

The absorption bandwidth and effectiveness of the metamaterial absorber are impacted by the material choice since various materials have varied absorption properties. For instance, to produce broad absorption bandwidths, materials with strong electrical conductivity, such as metals, are frequently utilized. Conversely, narrowband absorbers with great absorption efficiency may be created using dielectric materials.

For metamaterial absorbers, materials with strong damping and low losses are preferred. Low-loss materials maximize absorption efficiency by reducing electromagnetic wave reflection and transmission. A further factor in efficient absorption is the use of materials with strong damping qualities to release the absorbed energy as heat.

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reflection and transmission. A further factor in efficient absorption is the use of materials with strong damping qualities to release the absorbed energy as heat.

The metamaterial absorber may be required to tolerate mechanical stress or extreme environmental conditions, depending on the application. In such circumstances, mechanical strength, durability, temperature stability, resistance to moisture, chemicals, and other environmental conditions should all be taken into consideration when choosing materials.

It is important to think about the price and accessibility of the supplies. It could be important to choose materials that are affordable and easily accessible in the appropriate amounts, depending on the project's needs[24].

Chapter 3

3.1 Methodology

Establishing research goals, conducting a literature review, selecting appropriate materials, designing the absorber geometry, fabricating the structure, evaluating its performance, optimizing the design through simulations and experiments, performing parameter sensitivity analysis, investigating application and integration options, documenting findings for publication, and taking into consideration the need for additional research are all steps that are included in the methodology for investigating metamaterial absorbers. This scientific technique makes it possible to construct materials that successfully absorb electromagnetic waves and have the potential to be used in a wide variety of fields of study. This facilitates both the expansion of our understanding of metamaterial absorber technology as well as its further development.

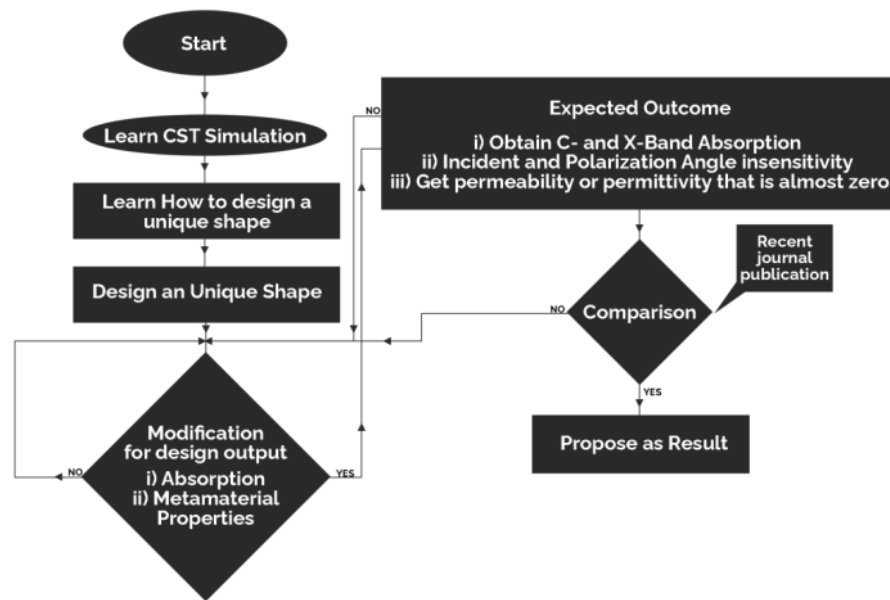


Figure 15. Methodology to design a perfect absorber

The investigation of metamaterial absorbers involves a procedure that may be broken down into a number of distinct but interconnected steps. During the initial stage of the research

process, the frequency range, efficiency, and bandwidth that are intended for absorption are determined. The subsequent phase is a comprehensive examination of the relevant material, the purpose of which is to evaluate the level of present comprehension and identify any knowledge gaps. When selecting the material, it is important to keep in mind both the anticipated frequency of operations as well as the attributes that are desired. The next step is the creation of the structure ³⁸ of the absorber's unit cell, which often involves the use of simulation software in order to fine-tune a number of different configurations. Fabrication techniques like as lithography and 3D printing are used in the production of the actual physical structure. Experimentation is used to characterize the absorber, which often includes taking measurements of both reflection and transmission. The results of this analysis are used to assess the absorber's performance. Researchers constantly iterate the process of refining both the design and the manufacturing procedures in order to get optimal results. This is done by using simulation and modeling to validate their findings. The process of analyzing how the results vary depending on how certain parameters are altered is called sensitivity analysis. The potential for applications and integration is investigated, and the findings are meticulously documented for future publication. The subject of metamaterial absorbers is then advanced by taking into consideration prospective future research paths and obstacles. This methodical technique blends theoretical, computational, and experimental aspects in order to produce materials with particular absorption properties for a variety of purposes. These materials may be used in a variety of settings.

1. **Specify the objectives of the study as follows:** Please make the objectives of your research very clear. At which specific wavelengths or frequencies would you want the metamaterial absorber to be effective? What would be the optimal bandwidth and the efficiency of the absorption?
2. **A review of the relevant published material:** Conducting a comprehensive literature review is the best way to get an understanding of the state of the business, the models that are already in use, and any new advancements in metamaterial absorbers. You might use this to identify gaps in your knowledge and potential topics for further study.

3. **Option for the Material:** Make sure to utilize materials that are suitable for the design of the metamaterial absorber. The performance of metamaterials, which often include periodic structures, may be affected by the choice of materials used in their construction.
4. **Structure and Arrangement:** It is necessary to identify the configuration of the metamaterial unit cell as well as the design requirements. It is important that the unit cells have the appropriate design, size, and shape in order for them to be able to absorb the requisite amounts of liquid. It may be possible to make use of simulation software such as HFSS, COMSOL, or CST Microwave Studio in order to produce an improved design.
5. **To create the illusion of:** Construct the metamaterial absorber with consideration given to the design parameters. Photolithography, electron beam lithography, and three-dimensional printing are all typical manufacturing technologies, but which one is used often depends on the size of the production run and how often it is performed.
6. **The following is a characterisation:** It is necessary to bestow onto the created metamaterial absorber a set of attributes before attempting to assess the performance of the absorber. Experiments are performed utilizing methods such as reflection and transmission spectroscopy to identify crucial properties such as the efficacy of absorption, the bandwidth, and other parameters.
7. **Optimization and fine-tuning are key terms here:** There is potential for the performance of the metamaterial absorber to be enhanced by modifying the design criteria and the manufacturing technique. In order to get the desired absorption properties, it is possible that this procedure will need a significant number of cycles.
8. **The following are examples of simulated and modeled systems:** Through the use of electromagnetic modeling and simulation tools, the behavior of the metamaterial absorber should be modeled and verified. Check that everything is consistent by contrasting the results of the simulation with the data collected from the experiment.
9. **An examination of the sensitive relationship between the parameters:** Investigate the manner in which the performance of the absorber is influenced by

the modifications made to the different design parameters. It is possible that this will help in the process of discovering crucial components and trade-offs.

10. **Bringing together application components:** Investigate the possibility of using the metamaterial absorber in a variety of applications, such as imaging, energy harvesting, or stealth technology. Take into consideration the possibility of integration with other helpful systems or pieces of equipment.
11. **The publishing industry and the archiving sector:** Always remember to keep meticulous notes of the results and inferences drawn from your inquiry. Prepare research papers for publication in relevant academic journals and give presentations of your results at conferences as part of your efforts to improve scientific knowledge. This will allow you to share your discoveries with other scientists.
12. **Upcoming Duties and Tasks:** Talk about the several ways in which the technology of metamaterial absorbers might be improved, as well as the different fields in which research could go in the future. Determine if there are any problems or unanswered questions that may be resolved by doing more research.

It is essential to collaborate with experts in electromagnetic theory, materials science, and engineering throughout the research process in order to acquire knowledge and experience in all aspects of metamaterial absorber design and performance evaluation. This will allow one to obtain information and experience in all of the aspects that go into designing a metamaterial absorber and assessing its performance[25].

3.2 Unit Cell Design

In this work, a design for a gas stove burner with an inductive-tailed MM absorber is proposed. This design has the following desirable qualities: broadband absorption without the use of the lumped element; polarization angle insensitivity; metamaterial features; a larger effective medium ratio (EMR); and a subwavelength size. Copper is utilized for the patch and ground in a 9 x 9 mm construction that uses FR-4 as the substrate. This construction was carried out.

In order to produce a metamaterial absorber unit cell, a uniquely shaped patch of annealed copper is placed at the front of the structure, and a ground of annealed copper with a thickness of 0.035 millimeters is placed on the opposite side of the structure. As a dielectric,

a FR-4 substrate is used that has a thickness of 1.6 millimeters and is used in between. The formation of a dipole results from the cooperation of the capacitance that is used for the distribution of surface current in the intervals between the copper patch and the patch itself.

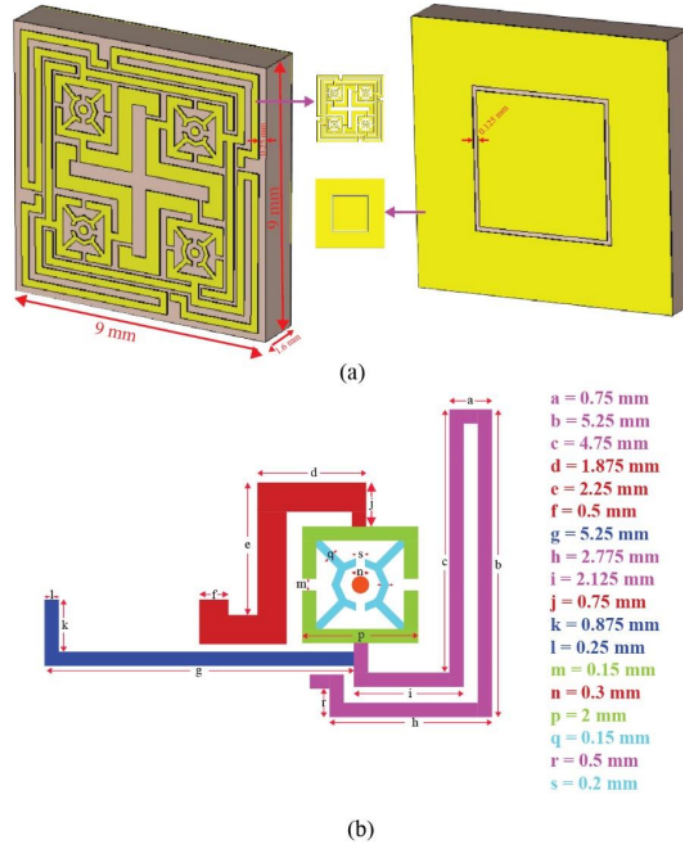


Figure 16. (a) Unit cell front and back view, and (b) parameter of the patch

The data shown in Fig.16.(a) illustrates In each of the four strips, which are formed in a rotating manner at angles of 0 degrees, 90 degrees, 180 degrees, and 270 degrees, there is a gas stove-shaped strip that is two millimeters in diameter, a dot with a diameter of 0.3 millimeters in the center of the strip, and an inductive tail that is linked to the stove. Because it is rotationally symmetric when seen from a number of different angles, the absorption that Phi and Theta display is identical. Given that the patch is not completely solid, it is possible that the incoming electromagnetic wave will not be reflected by it. Furthermore, given that the ground is a solid surface, the electromagnetic wave will not be

able to pass through it. The use of an imperfect ground contributes to the achievement of the highest possible absorption; further measurements are shown in Fig.16.(b).

3.3 Fundamentals of Absorption

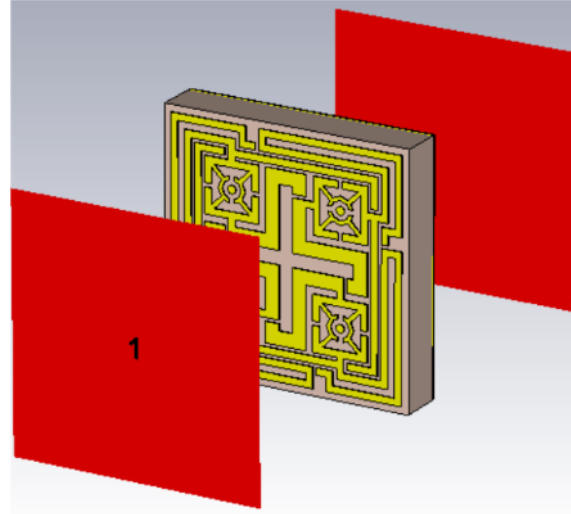


Figure 17. Port connection in the absorber

In order to obtain maximum EM wave absorption, it is necessary for both the metamaterial's reflection and transmission to be at their lowest possible levels. Following is an explanation of how to understand the absorption, which is represented by Equation 1.

$$A(\omega) = 1 - \Gamma(\omega) - T(\omega) \quad (1)$$

Here, $\Gamma(\omega)$ is the reflection coefficient ($|S_{11}(\omega)|^2$) and $T(\omega)$ is the transmission coefficient ($|S_{21}(\omega)|^2$). When the MM impedance is extremely close to the space impedance, as it is the case when the annealed copper is very close to the space impedance, there is very little transmission through it and very little reflection. This is because when the MM impedance is very close to the space impedance, the annealed copper is very close to the space impedance. This is shown by Equation 2, which can be found here.

$$\Gamma(\omega) = \frac{Z(\omega) - Z_0}{Z(\omega) + Z_0} \quad (2)$$

In order for there to be no reflection, it is necessary for the metamaterial absorber's space impedance and $Z(\omega)$ impedance to be equal to one another. The impedance of the

metamaterial absorber is influenced by a number of factors, including the relative permittivity and permeability of the empty space, as well as the frequency variation[26].

$$Z(\omega) = \sqrt{\frac{\mu_0(\omega) \mu f(\omega)}{\epsilon_0(\omega) \epsilon f(\omega)}} \quad (3)$$

The permeability and permittivity in free space are denoted by the symbols μ_f and, ϵ_f . whereas the permeability and permittivity that change with frequency are denoted by the symbols μ_o and, ϵ_o . As a direct consequence of this, the impedance of open space is,

$$Z_o = \sqrt{\frac{\mu_0(\omega)}{\epsilon_0(\omega)}} \approx 377 \quad (4)$$

3.3.1 Design Evolution

Designing broadband metamaterial absorbers for the C and X bands (with frequencies roughly ranging from 3.4 GHz to 12.4 GHz for the C band and 7.0 GHz to 11.2 GHz for the X band) typically requires building a complicated structure of metamaterial layers that can effectively absorb electromagnetic waves across these frequency bands. This is because lumped elements are not used in the process. To begin, you will need to build a structure with several layers, since this is the common pattern for broadband metamaterial absorbers. In order to achieve absorption throughout the C and X bands, it is necessary for each layer to exhibit their own unique features. Develop a basic building block, or unit cell, that may be applied several times over the whole structure. It is recommended that the unit cell be built out of structures or components that resonate at a variety of frequencies within the bands that are desired for use. Choose a dielectric substrate that not only provides the structure with mechanical support but also assures that it has an impedance that is matched to that of free space over the frequency range. Constructing substructures within the unit cell will give you resonance behavior in the C and X bands. Substructures that have the potential to be used include, but are not limited to, cross-shaped components, SRRs, and other geometries that are known to possess resonant properties. The arrangement of these substructures inside the unit cell and the distance between them is very necessary in order to accomplish broadband absorption. Adjusting the relative diameters of the substructures and moving them to different positions is required in order to exert control over the resonance frequencies. It is recommended that the features of the substructure, as well as

its geometries, be progressively modified between the layers. Because of this gradual shift, a wide frequency range is traversed without any jarring shifts. Utilizing software for electromagnetic modeling might result in an improvement to the design. Adjusting the dimensions and characteristics of the substructures allows for more control over the acquisition of the properties necessary for broadband absorption. When simulating the performance of the anticipated metamaterial structure, the C and X bands are the frequency ranges that should be used. Constructing prototypes and putting them through various kinds of testing will demonstrate that a material can absorb wideband signals. In order to create the structure polarization- and angle-insensitive, you should design it with additional symmetry or a large number of layers, if this is required for your application. When using the absorber in real-world scenarios, it is important to remember to take into account factors such as the angle of incidence and the surrounding environmental conditions. It is challenging to develop broadband metamaterial absorbers without using lumped elements due to the complexity of the structure as well as the need for precise tuning. Methods of optimization and simulation will need to be used in order to achieve the required performance characteristics that span both the C band and the X band. Experimenting with different substructure geometry and arrangement configurations is often necessary in order to achieve additional improvements in the absorber's overall performance.

3.3.2 The Solver List of CST Microwave Studio

CST Microwave Studio is an all-inclusive software program that can perform electromagnetic simulations in addition to microwave and radio frequency engineering. It gives users access to a wide variety of electromagnetic analysis solvers and tools, allowing them to manage a variety of various aspects of the field. Among these solvers are the Time Domain Solver (TDS), which is used for transient simulations; the Frequency Domain Solver (FDS), which is used for frequency domain analysis; the Eigenmode Solver (EMS), which is used for determining resonant frequencies and mode shapes; the Integral Equation Solver (IE), which is used for issues such as scattering and radiation analysis; the Asymptotic Solver (AS), which is used for radiation patterns and far-field results; Some versions of CST Microwave Studio come with extra capabilities such as the Thermal Solver (TS) for thermal analysis, the Particle-in-Cell Solver (PIC) for charged particle dynamics,

and optimization tools for design enhancement. All of these features may be found in ² CST Microwave Studio. CST Microwave Studio is a powerful piece of software that combines the capabilities of these solvers with those of meshing and pre-processing, making it suitable for ¹⁰ a wide range of applications involving the design and analysis of electromagnetic and radio frequency (RF) systems.

3.4 Softwares

3.4.1 CST Studio Suite 2020

Simulation and investigation of multiphysics and electromagnetic phenomena are carried out with the assistance of a powerful piece of software known as CST Studio Suite. Finding answers to challenging questions pertaining to electromagnetic fields is a major focus of this area of research, which is applied to a wide range of different areas and industries. The following is a synopsis of the CST Studio Suite in its simplest form:

² CST Studio Suite is able to do advanced electromagnetic simulations for a wide range of frequencies, ranging from static frequencies to optical frequencies. These simulations may be performed on any kind of frequency. It is able to represent the behavior of electromagnetic fields in a variety of contexts, including those involving antennas, RF/microwave circuits, waveguides, and other components. Users are able to investigate interactions between electromagnetic fields and other physical phenomena such as thermal, mechanical, and fluid dynamics by using the multiphysics simulations that are included in the CST Studio Suite. These simulations are in addition to the electromagnetic simulations that are included in the CST Studio Suite. CST Studio Suite is suitable for a broad variety of applications, ranging from DC (Direct Current) to high-frequency microwave and millimeter-wave devices because to the extensive frequency range that it covers. It finds use in a wide number of industries, including as electronics, automobiles, aircraft, healthcare, and telecommunications, among others. Using CST Studio Suite, it is possible to design and optimize a wide variety of components, including antennas, filters, and sensors, among other things. Users are able to simply set up simulations, show results, and assess data since the application includes a graphical user interface that is both straightforward and user-friendly. It has a large variety of capabilities for visualization and post-processing to choose from. When it comes to accurately modeling the dynamics of

electromagnetic fields, CST Studio Suite makes use of some of the most advanced numerical solvers available. There are a number of different kinds of solvers that are supported, including the ²² finite element method (FEM), the finite integration technique (FIT), and others. Users may conduct out parametric research and optimization efforts in order to fine-tune designs and achieve specified performance standards. The program has a seamless connection with well-known computer-aided design (CAD) tools, which enables users to import and work with ² 3D CAD models. CAD stands for computer-aided design. In educational institutions, ² the CST Studio Suite is used for the purposes of doing research in electromagnetics and other fields that are linked to electromagnetics as well as for the teaching of electromagnetic theory. Because it permits parallel processing, users are able to make better use of high-performance computing (HPC) capabilities, which helps them to simulate large and sophisticated models in a shorter amount of time. Scripting tools may be used by more experienced users in order to automate and personalize certain procedures and simulations. With the assistance ²⁴ of the versatile and widely used electromagnetic simulation tool CST Studio Suite, ²⁴ engineers and researchers from a wide range of fields are able to design, develop, and upgrade electromagnetic systems and components. It is very necessary for the development of electromagnetic research as well as the production of innovative forms of technology[27].

3.4.2 Origin Pro

In the fields of science and engineering, researchers often make advantage of the comprehensive data analysis and charting capabilities that Origin Pro provides. It is capable of data import and manipulation, statistical analysis, curve fitting, peak analysis, signal processing, image analysis, and both 2D and 3D data presentation. Because it provides a wide range of features for advanced data exploration and presentation, Origin Pro is suitable for tasks such as data exploration, hypothesis testing, and the production of graphs and reports of publication-quality. Since it also supports a range of data formats and gives scripting options for automation and customization, it is a helpful tool for specialists in academia, business, and research who need to analyze and show complex information. This is because it is necessary for these professionals to analyze and present the information[28].

3.4.3 ADS Circuit Simulation

A comprehensive electrical design automation (EDA) tool known as Advanced Design System (ADS) offers a variety of powerful functions for the modeling and design of circuits. Electrical circuits with a focus on RF and microwave applications may be designed, evaluated, and improved with the help of this software. ADS includes huge component libraries, provides a user-friendly environment for schematic capture, and supports parameter sweeps and optimization for the purpose of design exploration. It offers electromagnetic (EM) simulation that is seamlessly integrated with frequency-domain and time-domain simulations, as well as nonlinear analysis, with the purpose of providing accurate characterization of both passive and active components. ADS is a critical tool for RF and microwave circuit designers to produce high-performance designs and conduct sophisticated simulations for a range of applications because it enables statistical analysis, promotes co-simulation with other tools, and allows for customization via scripting. These features make ADS an essential tool for RF and microwave circuit designers[29].

Chapter 4

4.1 Result Analysis

4.1.1 Reflection Coefficient (S11)

The reflection coefficient of an absorber is what determines how much electromagnetic energy is reflected when it interacts with the absorber. This happens when the electromagnetic energy comes into contact with the metamaterial. Absorbers made of metamaterials are man-made items designed to successfully absorb certain frequencies or wavelengths of electromagnetic radiation, such as microwaves or infrared light. If the reflection coefficient is low, then the majority of the incident radiation will be absorbed by the metamaterial. On the other hand, if the reflection coefficient is high, then a large portion of the incident radiation will be reflected. Absorbers made of metamaterials find use in a wide range of applications, including energy harvesting and stealth technologies, in which it is vital to minimize reflection in order to achieve the highest possible level of performance.

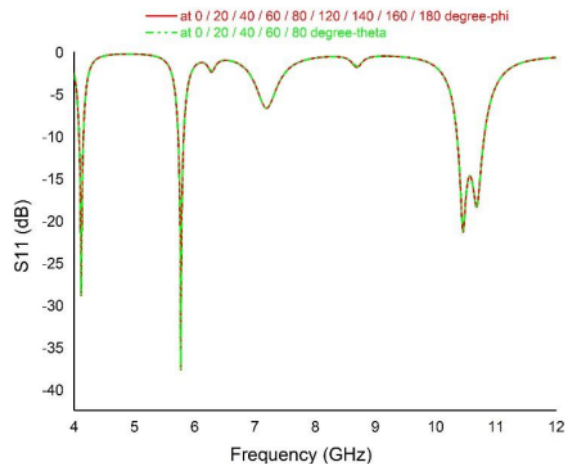


Figure 18. Reflection coefficient at TEM mode

At a variety of frequencies, when absorption is at its peak, each split performs the role of a resonator. A huge number of alterations were made to the problematic ground in order to achieve the highest possible broadband absorption as well as a negative value for permeability or permeability. It is clear from looking at Fig.18, that a total of four resonance

frequencies were accomplished in the C and X bands. These frequencies were achieved at 4.12 GHz, 5.776 GHz, 10.472 GHz, and 10.696 GHz respectively.

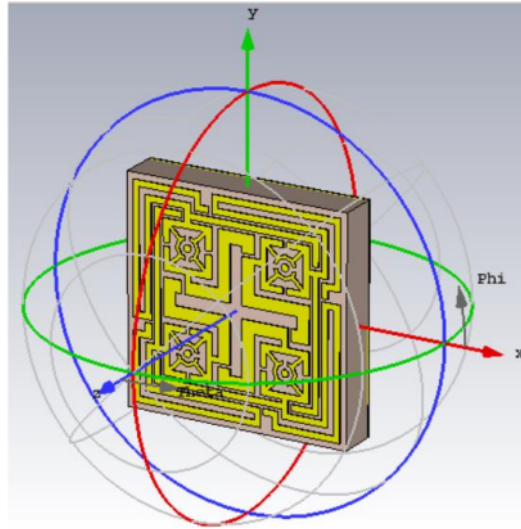


Figure 19. Farfields of designed absorber

The farfields of an absorber in a metamaterial model depict the way in which electromagnetic radiation is scattered in regions that are physically separated from the absorber. It is vital to have a firm grip of these fields in order to have an understanding of how the absorber interacts with electromagnetic waves that are entering the system. Metamaterial absorbers are capable of successfully absorbing and dissipating incoming radiation, most of the time by converting the energy into heat. The efficacy of the absorber in the farfields may be shown by a decrease in the amount of energy that is reflected and transmitted. This results in a reduction in the radar cross-section and an improvement in signal emission or reception. This property is essential for applications such as stealth technology, which requires a significant reduction in the amount of radar reflection, as well as for communication systems, which need a significant improvement in the transmission of signals. The farfield characteristics of metamaterial absorbers make it possible for advancements to be made in radar systems, antennas, and the manipulation of electromagnetic waves. These qualities are essential for knowing how effective metamaterial absorbers are and for adapting their designs for specific needs.

4.2 Transmission Coefficient

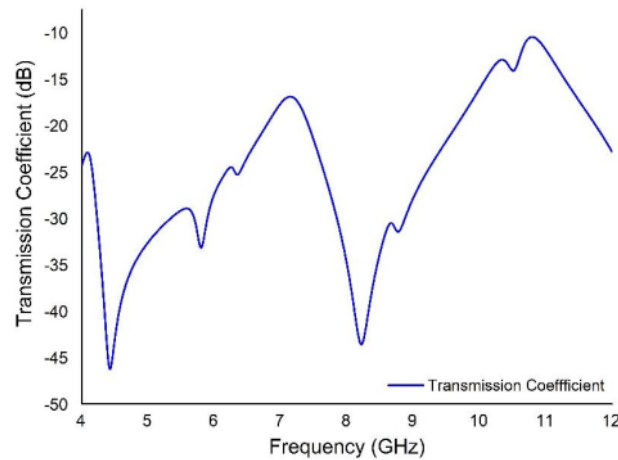


Figure 20. Transmission coefficient at TEM mode

Condition to count the resonance frequency as an absorber is that the transmission coefficient of the resonance frequencies is below -10dB which we can see in Fig.20. The transmission coefficient of a metamaterial absorber refers to the percentage of electromagnetic energy that is transmitted through an absorber in comparison to the amount of energy that is incident onto the absorber. For the purpose of effectively absorbing certain frequencies or wavelengths of electromagnetic radiation, such as microwaves or infrared light, engineered materials with the catchy name "metamaterial absorbers" have been developed. Because of the unique qualities of their structure, they are capable of achieving an absorption rate of over one hundred percent while allowing for just a little amount of transmission. Since the transmission coefficient measures how effectively the metamaterial can block the passage of incoming waves, it is an important factor in determining how effectively the absorber performs. This property makes the metamaterial a useful component in applications including radiation protection, energy harvesting, and stealth technology. A higher number implies that a larger amount of energy is transported through the material rather than absorbed by it, while a lower value suggests that the material is a very efficient absorber of energy.

4.3 Absorption

The amazing phenomena known as metamaterial absorption is only made possible by a newly discovered class of materials known as metamaterials. These materials were created on purpose and are referred to by their technical name. Because these materials possess unique electromagnetic properties that cannot be found in nature, they are able to absorb electromagnetic waves effectively within specific frequency ranges. This ability allows them to be used in a variety of applications. They are therefore able to successfully cover a variety of frequency bands as a result of this. The production of metamaterial absorbers with an almost flawless absorption rate of one hundred percent is possible through the employment of structures that are capable of not only absorbing incoming radiation but also releasing the energy that was absorbed as heat. Creating these absorbers calls for a high level of dexterity and handiwork on the part of the craftsman. This technology provides a great degree of customizability, which makes it particularly valuable in applications such as stealth technology, where it minimizes radar reflections, as well as in fields such as energy harvesting, sensing, and imaging. Stealth technology is only one example of an application that could benefit from this technology. The capability of this technology to enable correct tuning for absorption within predetermined frequency ranges is another factor that contributes to the significance of the technology.

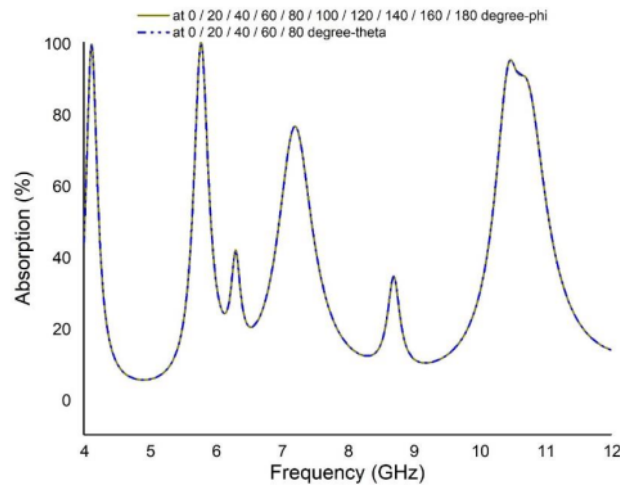


Figure 21. Absorbency at typical incidence (TEM mode)

Metamaterial absorption has paved the way for the creation of cutting-edge solutions in a variety of industries because of its unrivaled capacity to control and make use of electromagnetic energy. This ability has made it possible for metamaterials to be used in a number of applications. As can be seen in Figure 21, there is absorption that occurs across a broad frequency range taking place between the frequencies of 10.373 GHz and 10.825 GHz. The range of absorption and the proportion that it accounts for remain the same whenever electromagnetic waves come into contact with one another, regardless of the angle of polarization. The intended MM is currently referring to itself as an MM absorber with maximal absorptances of 99.4%, 99.9%, 95%, and 90.4%, respectively, at 4.12 GHz, 5.776 GHz, 10.472 GHz, and 10.696 GHz. These frequencies range from 4.12 GHz to 10.696 GHz.

4.4 Permeability

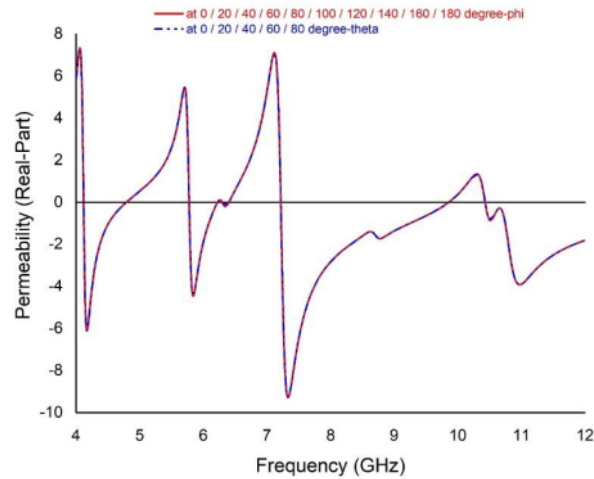


Figure 22. Relative permeability

When we look at Fig.22, we can see that the permeability values at resonance frequencies are very close to zero, which is a telltale sign that we are dealing with metamaterial qualities. The permeability of a metamaterial absorber is an important attribute, and it is one of the qualities that contributes to the amazing absorption capacities that the absorber possesses. Metamaterial absorbers are designed to have certain magnetic responses, the majority of which are defined by a low permeability. These responses are achieved by

engineering the absorbers to have a low permeability. They are able to exert effective control over the magnetic component of incoming electromagnetic waves because of this one-of-a-kind characteristic, which enables absorption across a large frequency range and makes it possible for the material to operate across those frequencies. Because of this, they are able to effectively govern the magnetic component of the waves that are coming their way. Absorbers made of metamaterials have the potential to successfully gather electromagnetic energy and transform it into heat. This can be accomplished by altering the permeability of the material through the building of subwavelength structures and the regulation of resonances. Metamaterial absorbers are flexible instruments that may be used for a variety of purposes, including electromagnetic shielding, stealth technology, and efficient energy harvesting. This is made possible by the control that can be exerted on permeability as well as other electromagnetic properties. Electromagnetic waves, because to their capacity to produce artificial magnetic responses, now have a larger variety of applications than they did in the past, particularly in terms of the manipulation and absorption of electromagnetic waves.

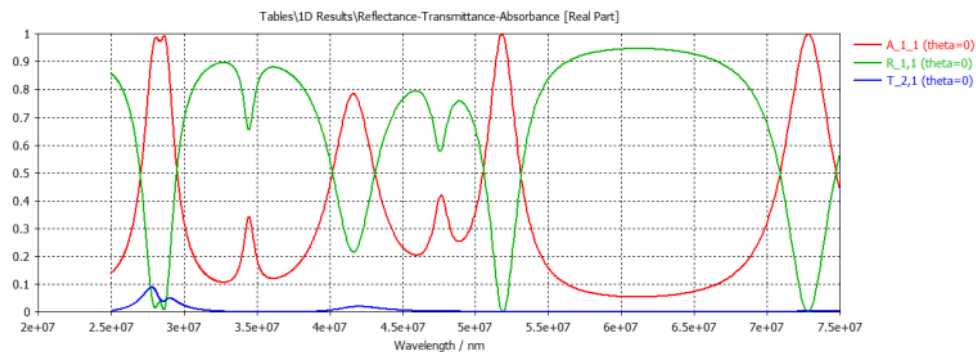


Figure 23. Reflection, absorption, and transmission

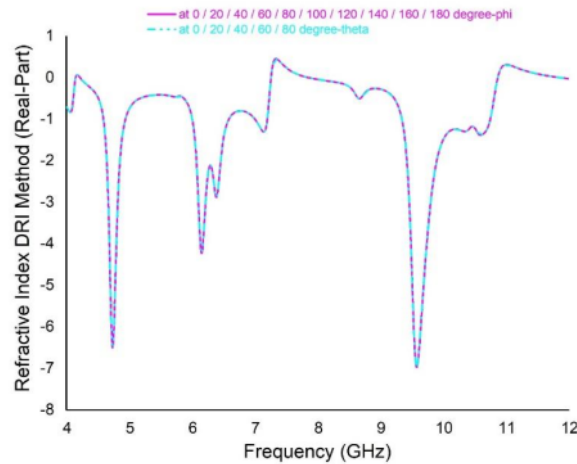
CST Microwave Studio's reflection, absorption, and transmission graphs are of the utmost significance when it comes to the planning and investigation of metamaterial absorbers. These graphs may be found in the software. With the help of these diagrams, an in-depth description of how the absorber responds to electromagnetic waves that are being introduced into the system may be provided. The graph of the reflection coefficient provides information on the anti-reflective properties of the absorber by indicating the

amount of incident energy that is reflected off of its surface. Utilizing this knowledge will help one comprehend the functioning of the absorber in greater detail. The graph of absorption also displays the absorber's capacity to distribute incoming electromagnetic energy, which enables engineers to examine how well the absorber attenuates a particular frequency or a range of frequencies. Another helpful tool for illuminating the link between transmission and absorption in terms of establishing equilibrium is the graph of the transmission coefficient. This graph depicts the percentage of energy that is transported from the source to the sink, and it is one of the tools that can be used to analyze the relationship between transmission and absorption. These graphs are of significant aid in the process of tuning metamaterial absorbers for a variety of applications, such as the shielding of electromagnetic interference (EMI), the development of stealth technologies, and the customisation of absorption across a number of frequency bands. Specifically, the shielding of electromagnetic interference (EMI) is ⁹one of the most important applications of metamaterial absorbers. Engineers have the capability of fine-tuning the design parameters in order to achieve the necessary performance characteristics in the key applications that are based on metamaterials. This is accomplished by paying great attention to both sets of graphs. When we look at Figure 23, we can see that the transmittance is at its lowest point where we acquired resonance, and that the absorption is at its highest point in locations that are similar to these points.

4.5 Refractive Index

Finding the point at which ¹the relative permeability or permittivity value is almost zero or negative is essential when attempting to ascertain the amount of absorption that is at its greatest point. This is because finding this point is the only way to get an accurate reading on the amount of absorption that is at its highest point. We were able to ascertain that the value of our refractive index was negative by doing a comparison of the resonance frequency that we had acquired. This was possible because of the fact that the value of our resonance frequency was negative. Figure 24 illustrates this finding, which reveals how we arrived at this inference as a result of our investigation. Each resonance frequency has a single negative value, which is commonly abbreviated to the SNG notation and can be positioned anywhere within the frequency. This value is sometimes referred to as the SNG

notation. The MM absorber that has been suggested for use in this inquiry demonstrates a value for μ (a permeability) that is less than zero at ¹ each resonance frequency when the -10dB value of S11 and S21 is taken into consideration. This finding was made possible as a result of the fact that the value of S11 and S21 was found to have been taken into consideration. Because it exhibits a value for μ (a permeability) that is smaller than zero at each resonance frequency, it has been suggested that this absorber be utilized, and it has been given a recommendation to do so.



⁹ **Figure 24.** Refractive Index with respect to frequency

The refractive index of a metamaterial absorber is an important component that plays a part in determining how electromagnetic waves interact with the absorber. This interaction is determined by the absorber's ability to transmit and absorb electromagnetic waves. Metamaterials, on the other hand, have the potential to display unexpected refractive properties, such as negative or almost zero refractive indices. This is in contrast to the conventional features of materials, which typically have positive refractive indices. On ² the other hand, the refractive indices of ordinary materials are often on the positive side. This one-of-a-kind capability is the consequence of purposefully building subwavelength structures inside the metamaterial. This provides the material the power to bend and manipulate light or electromagnetic waves in ways that were not previously feasible. It is possible to construct metamaterial absorbers that have the capability to refract, absorb, or modify incoming radiation with pinpoint accuracy if the index of refraction is precisely

controlled during the manufacturing process. This ability is especially helpful in situations where conventional materials fall short, such as the design of cloaking devices that can turn objects invisible to specific light or electromagnetic waves or the construction of superlenses for sub-diffraction imaging. Both of these examples include the use of conventional materials. The cloaking devices and the superlenses are two examples of situations in which standard materials are inadequate. In both of these examples, the cloaking devices are used. Our knowledge of the mechanisms involved in optical and electromagnetic phenomena has increased as a direct result of our capacity to produce refractive indices in metamaterial absorbers. In addition, this skill has made it possible to build novel solutions for a wide variety of cutting-edge technologies, which has contributed to the advancement of such technologies.

4.6 Surface current

When operating in TEM mode, the total bandwidth of absorption is about 0.618 GHz, and this value remains constant regardless of the EM wave's incidence angle. In Fig.21, we can see that the shape of a plus sign in the middle of the patch has very little influence on surface current at 4.12 GHz. However, the reason for this plus sign is that it has some more influence on other resonance frequencies (5.776 GHz, 10.472 GHz, and 10.696 GHz) in the patch, and in order to get the right ratio of capacitive and inductive element to get the required result, this sign helps to reduce the lacking of the inductive element in the patch. We can see how the damaged ground also has an influence on the surface current in the ground figure because the resonance frequency is changing towards the lowest area as a result of the damage. This allows us to observe how the damaged ground has an impact on the surface current. The ground transmission through it also changes, and since the patch also has some cuts, this has an influence on the reflection in the recommended MM absorber. The outcome of the simulation is shown in Fig.17, and it demonstrates that the suggested absorber is capable of broadband absorption and is also insensitive to polarization at any angle. As demonstrated in Fig.21, in order for a material to demonstrate the characteristics of a metamaterial, the permittivity or permeability at the resonance frequency must be close to zero (NZR) or negative. As can be seen in Fig.21, the surface current is an essential component in the process of attaining the resonance frequencies.

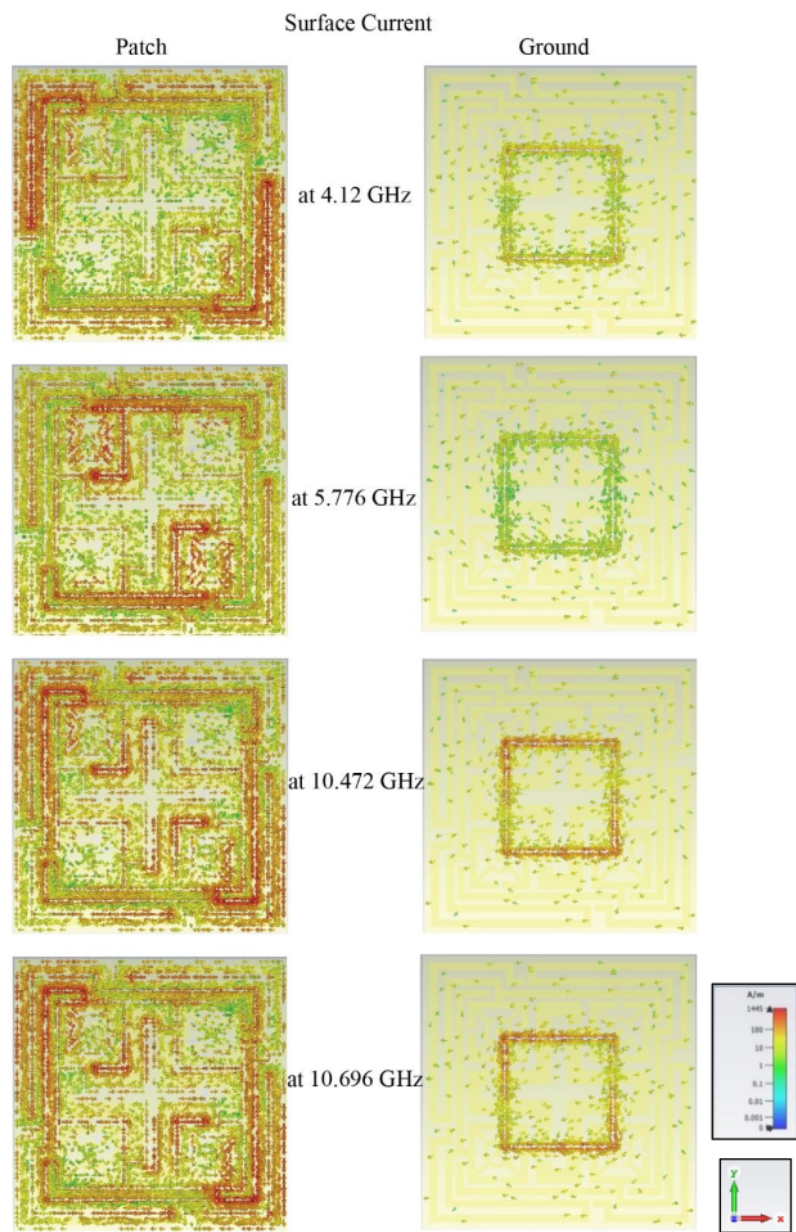


Figure 25. Surface current at different resonance frequencies

4.7 Table of Comparison with other absorbers

Ref	Year	¹ Resonance Frequency GHz	Size of the Unit Cell	SNG or DNG Values	Substrate and Thickness	Broadband Absorption Without Lumped Element	Maximum Polarization Angle Insensitivity	EMR
[30]	2020	2.4 & 5.1	18 mm (0.14 λ)	Not Mentioned	¹ Double-Layered Rogers RO 3003 (1.75 mm)	No Broadband Absorption	90°	6.94
[31]	2022	5.376, 10.32 & 12.25	10 mm (0.179 λ)	Not Mentioned	¹ FR-4 (1.6mm)	No Broadband Absorption	60°	5.58
[32]	2022	8.3, 9.2, 9.88, 10.66, 11.16, & 11.85	22 mm (0.6 λ)	Not Mentioned	¹ FR-4 (1.6 mm)	No Broadband Absorption	90°	1.64
Proposed	2023	4.112, 5.768, 10.456 & 10.68	9 mm (0.12 λ)	SNG	FR-4 (1.6 mm)	Yes	180°	8.1

Because of the unexpected results that we found, it is clear that the absorber that has been recommended is exceptional and ranks higher than others. In order to determine whether or not ¹ the suggested metamaterial absorber is successful, we evaluate this finding in light of many earlier pieces of research. achieved polarization insensitivity, which is not shown in Table1; this was a successful endeavor. ¹ The MM absorber is easy to use as a sensor and also functions well in satellite communication owing to its compact design and the use of a single layer of FR-4 as the dielectric medium. Both of these benefits may be attributed to the fact that the ¹ FR-4 is used as the dielectric medium. Because it enables a more compact structure, better EMR makes it easier to utilize this absorber as a sensor. This is because better EMR promotes the usage of this absorber. In this study, broadband absorption was achieved without the use of any lumped components, which is still another advantage of avoiding the use of lumped elements altogether[33].

Chapter 5

5.1 Conclusion

The construction and simulation of a unit cell are carried out with the help of CST Studio Suite 2020. The values of S11 and S21 are taken from the CST parameters, and the values of permittivity, permeability, absorption, and refractive index are found by using the MATLAB tool. In Origin Pro, the graph is built using these data as its building blocks.

The outcome we achieved and the design we came up with are unremarkable and have never been seen before without the use of components (R, L, G, C). In order to obtain great EMR and satisfy the subwavelength size criterion, the design was purposefully made to be as small as possible. Because of this, it requires less room than the majority of other contemporary devices do wherever it is deployed. Because it functions as a broadband X band absorption, it has the potential to be an efficient tool for reducing electromagnetic interference (EMI) and electromagnetic compatibility (EMC) in a variety of electromagnetic applications. Because of its maximum sensitivity of 180 degrees, it has the potential to be used as the most effective absorber. There are a lot of different applications that may be used for the C and X bands, and there will be many more in the future. Therefore, it is quite conceivable that one may make effective use of this apparatus provided that one did so in a prudent manner. It may be used to a variety of different fields at the present time. This study offers a novel MM absorber that has wide incidence angle applicability for the C and X bands of the electromagnetic spectrum. As a result of the fact that each quadrant is symmetrical, the angle is unaffected by the progression of the electromagnetic wave. Because it is not sensitive to polarization or angle, this will help in the effort to decrease the number of applications that cause electromagnetic interference. Earth station transmitters, C band satellite downlink, Wi-Max, WLAN application, amateur satellite operation, and radar application were the four resonance frequencies that we found[34]. The other two resonance frequencies came in at 10.472 GHz and 4.12 GHz respectively. There are now a lot of satellites that operate in the C band, which is advantageous since it has a narrower bandwidth compared to other bands and has the quality of producing less interference when there is really strong rain fading. The use of X

band frequency in military communications is highlighted further by a number of strategic and technical considerations[35].

5.2 Accomplishments of this Thesis

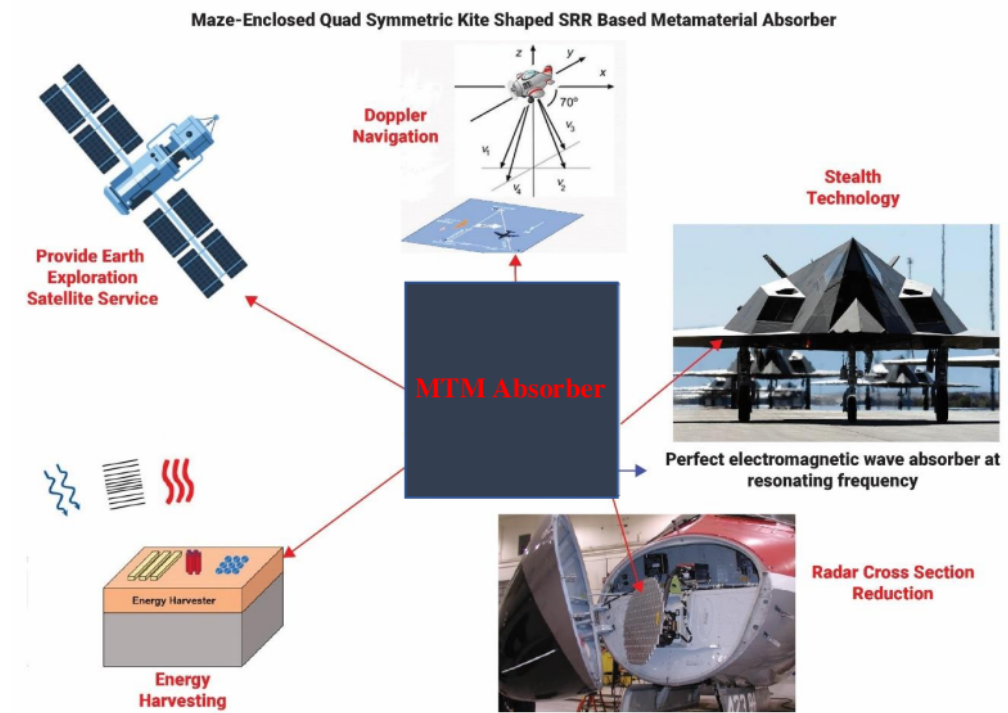


Figure 26. Applications

Here in Figure 26, we could discover a number of applications in which we may apply our suggested absorber in this research for real-life applications. These applications can all be found in the same place. To create a civilization that is sustainable in today's world, which is powered mostly by renewable sources of electricity, this sort of material is required[36].

In this book for my thesis, we investigate the innovative notion of attaining broadband absorption without the normal lumped components, polarization constraints, or sensitivity to incidence angles. In this research, we want to develop a unique metamaterial absorber that is capable of overcoming the limitations that are associated with conventional engineering. We have created a unique absorber by making use of the properties that are inherent to metamaterials[37]. This absorber is capable of successfully absorbing

electromagnetic waves over a wide spectrum and does so without the need for extra components or specific wave orientations. This invention not only has the ability to open up new prospects for applications ¹¹ in a wide range of fields, such as stealth technology, communication systems, and energy harvesting, but it also has the potential to completely transform the way absorber technology is developed. Our finding is a significant step forward in the continuing quest for flexible and high-performance absorbers. It also contributes to the advancement of the area of metamaterial research and the practical applications of this study[38].

5.3 Accomplishments of Metamaterial Absorbers

The capacity of engineered materials to alter the environment is shown by the remarkable achievements that have been made using metamaterial absorbers in a range of different domains. These absorbers have made it feasible to create radar-absorbing materials, which in turn lessen the radar cross-section of aircraft and vehicles, so redefining how military operations are conducted. Stealth technology has been significantly advanced as a result of these absorbers[39]. They have led the way for novel antenna designs in the realm of telecommunications, boosting signal transmission and reception for satellite technology and leading to more effective communication systems. In recent ¹⁴ years, metamaterial absorbers have emerged as important contributors to energy harvesting. These absorbers are able to effectively catch and convert ambient electromagnetic radiation, such as Wi-Fi signals or sunlight, into electrical energy. This allows for the generation of electricity in a sustainable manner. They have revolutionized medical imaging and sensing technologies, which has led to improvements in both the accuracy of diagnostics and the quality of patient treatment. The employment of metamaterial absorbers is the key to boosting the efficiency of solar panels in the quest for renewable energy, which will in turn encourage a greater use of clean energy sources. Through ongoing advancements in their respective fields and an increasing number of projects geared toward commercialization, materials are demonstrating their capacity to play a pivotal role as future contributors to both the advancement of technology and the preservation of the natural environment[40].

5.4 Future working Scope

In the fascinating field of metamaterials, a novel gadget known as a metamaterial absorber has emerged as a possible game-changer for a wide variety of various industries. Because these man-made compounds were conceived with the intention of affecting electromagnetic waves in certain ways, they are well suited for absorbing and controlling electromagnetic radiation. I will explain the future working scope in the field of metamaterial absorbers, even though I am aware that there may have been major advancements since the last time I updated my knowledge in September 2021.

⁹ One of the potential applications for metamaterial absorbers is in the creation of cutting-edge antenna technology. Antennas that are based on metamaterials provide improved performance attributes, which is particularly important in light of the rising need for faster and more efficient wireless communication. Modifying these antennas such that they operate in certain frequency bands might potentially increase both the signal strength and range of the devices[41].

Both the military and the aerospace industry have a strong interest in metamaterial absorbers because of the potential for these materials to reduce the radar cross-sections of aircraft and other assets. In the not-too-distant future, the creation of stealth materials that are even more effective might result in an expansion of the capabilities of the national security apparatus.

For the purpose of energy collection, metamaterial absorbers are now being used, and attempts are being made to continue doing so. These materials have the capability of absorbing electromagnetic radiation from a variety of sources, such as Wi-Fi signals or sunlight, and transforming it into usable electrical energy. This might lead to the development of energy harvesting systems that are more effective and more compact, which would be beneficial to the creation of sustainable energy sources[42].

Metamaterial absorbers have the potential to usher in a new era of technological innovation in the fields of imaging and sensing. These materials have the ability to manipulate electromagnetic waves, which enables them to create clearer images and sensors with a higher degree of accuracy in fields such as remote sensing, security scanning, and medical

imaging. It's possible that as a consequence of this, we'll have improved safety precautions, enhanced monitoring of the surrounding environment, and more accurate medical diagnoses.

It is possible that the solar energy industry may see significant development as a result of the use of metamaterial absorbers. The researchers are looking into the most efficient ways that these materials may collect solar energy and transfer it into usable forms. If we are successful in this endeavor, it may lead to the development of solar panels that are both more cost-effective and efficient, which will ultimately increase the use of renewable energy sources[43].

Absorbers made of metamaterials have potential applications in a variety of biomedical technologies, including non-invasive sensing systems and hyperthermia therapy for the treatment of cancer. These mobile applications have the potential to revolutionize medical practice by delivering diagnostic and treatment methods that are both more reliable and less risky.

In the context of metamaterial absorbers, the terahertz frequency band is of significant significance. The results of future study in this field might lead to advancements in terahertz imaging, communication, and spectroscopy, all of which have the potential to be useful in the screening process for both criminals and patients.

As the need for flexible and wearable electronics continues to grow, metamaterial absorbers may come to play a more significant role in the development of efficient and compact electronic devices. This category includes not only gadgets that monitor your health but also tools for communication and even apparel that incorporates technological elements[44].

As a consequence of the continuous research that is being conducted in the field of metamaterial design and the creation of materials, it is anticipated that absorbers that are both more effective and more easily tunable will be generated. As a consequence of advancements in materials science, these materials will find an increasing number of applications in practical settings, opening the door to further levels of customization and optimization of performance[45].

As the technology behind metamaterial absorbers continues to advance and become more broadly accessible, there will be greater opportunities for commercialization. Businesses have the potential to create and commercialize goods based on metamaterial absorbers, therefore satisfying the needs of a wide variety of industries[46].

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- [1] Gas Stove Burner Shape with Inductive Tailed Rotational Symmetric Metamaterial Absorber for C and X Band Application
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