A Thesis report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

Submitted by

T M Nazmul Hassan
191-33-4909
Tanvir Mahmud Meem
191-33-5139

Submitted to

Dr.Tama Fouzder
Associate Professor
Department of Electrical and Electronic Engineering
Faculty of Engineering

Department of Electrical and Electronic Engineering
Faculty of Engineering
DAFFODIL INTERNATIONAL UNIVERSITY

FEBRUARY, 2023

Declaration

We hereby declare that this thesis paper **“Metamaterials for antenna band frequency improvement**” represents our own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. we have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged our obligations and the rights of the participants.

Nazmul

T M Nazmul Hassan
191-33-4909
Department of Electrical and Electronic Engineering
Faculty of Engineering
Daffodil International University, Bangladesh

Tanvir

Tanvir Mahmud Meem
191-33-5139
Department of Electrical and Electronic Engineering
Faculty of Engineering
Daffodil International University, Bangladesh

Approval

The Thesis paper entitled **“Metamaterials for antenna band frequency improvement”** submitted by **T M Nazmul Hassan(191-33-4909) & Tanvir Mahmud Meem(191-33-5139)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **February, 2023.**

Signature

Tama Fouzder 08·02·2023

Dr.Tama Fouzder

Department of Electrical and Electronic Engineering
Faculty of Engineering
Daffodil International University, Bangladesh

Acknowledgement

Firstly, we would like to thank Almighty Allah, who has created us and provided me with the ability to complete o entire process and finish this report.

We want to thank our respected supervisor Dr. Tama Fouzder, Associate Professor Department of Electrical and Electronic Engineering, Faculty of Engineering, Daffodil International University. Her guidance has been of extreme help to me. We are thankful for all the times we consulted her, and she answered with utmost patience and perseverance. We also thank her for providing me with detailed instructions on how to proceed with our thesis and for supporting and helping is whenever we faced difficulties throughout the period.

Furthermore, we would not forget to thank our seniors, who was always there to show their support, which helped ease our whole thesis. Finally, we are also very grateful to our family and friends for their continuous support and love that kept on inspiring us.

Contents

List of Figures

List of Table

Abstract

Metamaterials are metal alloys with properties not generally seen in naturally occurring materials. Certain features, such as the ability to bend light or radio waves in a direction different from that of a standard material, are produced by the materials' unusual structural structure. They are widely used to alter energy waves of various types, including as light and sound. They are frequently used to modify energy waves of many kinds, including light, sound, and others. They were constructed with certain electromagnetic characteristics in mind. Components including waveguides, resonators, and filters are built using magnetic materials such as metals, crystals, and ceramics. As a result, to increase bandwidth and gain and reduce the size of traditional patch antennas, metamaterial structures are often loaded on or near the patch, implanted in the substrate, loaded from the ground plane, or etched off the ground plane. The use of metamaterials has enhanced the directivity, gain, bandwidth, and efficiency of antenna design in a variety of ways. The features of the metamaterials must be altered throughout the design process in order to ensure that the desired performance is reached. Two WLAN antennas diameters and bandwidths at the same 2.413 GHz resonance frequency before and after employing MTMs. When it reduces 20% of its size it gains 40% more frequency. Numerous antenna systems have been scaled down using methods including deformation, shorting walls, shorting pins, high-permittivity dielectric substrates, and others. Metamaterials have been widely used in the creation of antennas due to their distinctive electromagnetic properties. Electromagnetic metamaterials enable the design to perform better in terms of gain, directivity, bandwidth, and size reduction. The most recent research on the application of metamaterials to enhance antenna performance has been investigated and discussed in this study.

CHAPTER 1

Introduction

Worldwide designers are working to make antennas smaller as demand for wireless communications and portable, tiny wireless communications devices rises. Therefore, engineers are working very hard to create smaller and more efficient parts that can be used in these devices. The antenna is one of the most crucial parts of any wireless communication system. It should be small yet also offer great efficiency, plenty of gain, and broadband operation. In order to achieve these objectives, engineers are developing a variety of cutting-edge antenna designs that are more efficient and portable than the traditional dipole or monopole antennas. The microstrip patch antenna is one of the antennas that has garnered the most attention recently. This antenna is made up of a tiny patch of conducting material attached to an insulating substrate and a transmission line. The low profile, light weight, compact, conformable design, simplicity of production, and ability to be combined with solid-state electronics are only a few benefits of the microstrip antenna. The main advantages of this antenna are its low profile, light weight, and compatibility with other solid-state devices. However, due to their limited bandwidth, microstrip antennas have a serious drawback. Numerous techniques and studies to enhance the bandwidth have recently been conducted. In addition to employing a metal patch as the radiating element, these techniques also included adding an open-circuit stub or a meander line to the feeding network.

Over the past years, new materials known as "metamaterials" have appeared and are now widely used in a range of applications. Both significant antenna shrinking options and unique electromagnetic properties like a negative index of refraction are provided by metamaterials. A few particular properties that are not available in natural materials are present in these carefully designed composite structures. Metamaterials, often referred to as left-handed materials (LHM), double negative (DNG) materials, or synthetic materials with negative permittivity and permeability, were first proposed by Veselago in 1967. These materials have since been used for a wide range of purposes, such as sub-wavelength imaging, cloaking technology, and perfect lenses. Pendry and his coworkers updated the information in 1999, 32 years after the initial publication. They showed that precise permittivity and permeability values can be built into metamaterials, and that these materials can be utilized to build structures with unexpected properties. They arrived to the conclusion that negative permittivity and negative permeability can be achieved, respectively by using split ring resonators and a variety of metallic wires. This study was crucial in the development of metamaterials because it showed how to create and use metamaterials to obtain properties that did not exist in nature.

In response to this knowledge, Smith and his colleagues created a construction in 2001 using a split ring resonator and thin wire. This structure was developed by Smith and his coworkers in 2001 as the first example of a metamaterial with exceptional qualities because of its negative permittivity and permeability. The popularity of metamaterials is currently rising. Smith and his colleagues' work from 2001 made it possible to produce novel materials with characteristics that were not found in nature.

CHAPTER 2

Literature Review

2.1 Introduction

A literature review is a comprehensive summary of previous research on a topic. The literature review surveys scholarly articles, books, and other sources relevant to a particular area of research. The purpose of the literature review is to identify gaps in knowledge, explore the current state of understanding on a topic, and provide context for research being conducted. The review should enumerate, describe, summarize, objectively evaluate and clarify this previous research. It should give a theoretical base for the research and help identify any conflicting evidence or prior research about the topic. It should give a theoretical base for the research and help to determine the nature of research.

2.2 Metamaterials

In the fields of electromagnetics, material science, physics, and other interdisciplinary subjects, metamaterials have been used as an attractive solution to overcome the limitations of traditional antennas. (Innovation, 2022) [8].

2.3 The Left-Handed Metamaterial

The Left-Handed Metamaterial (LHM) has a few unique properties, including reverse waves and negative refraction (Alam et al.)[1]. This chapter addresses several LHM antenna applications as well as the fundamental concepts that underlie their unique characteristics.

2.4 Background of Left-Handed Metamaterial

A large class of metamaterials known as LHMs, or left-handed materials, exhibit reverse wave propagation and a negative index of refraction (Ltd, 2022). Left-handed metamaterials (LHM) or double-negative metamaterials are electromagnetic metamaterials with negative permittivity and permeability (DNG). This innovative technology makes it possible to build antennas with wide bandwidth and efficient radiation patterns, which is not possible with conventional antenna designs (Tatsuo Itoh, 2008)[13].

2.5 History of Left-Handed Metamaterial (LHM)

The original investigation on LHM was started by V. G. Veselago from the Lebedjev Physical Institute in Moscow by making theoretical predictions about this artificial substance with negative permittivity and permeability. Veselago asserts that the presence of this substance may result in a phenomenon known as negative refraction, in which the wave enters the medium and is bent in the opposite direction of its usual travel (Wikipedia, 2022) [14]. The notion of the left-handed drug gained prominence. The first experimental verification was carried out following this exciting discovery in 2001 by Shelby, Smith, and Schultz at the University of California (Szoplik, 2005) [12]. They used a material that contained split-ring resonators and a periodic arrangement of copper wires, and it was able to absorb electromagnetic radiation, proving the viability of Veselago's theory. A split ring resonator and thin wire make up the left-handed material structure, as seen in figure 1.1.

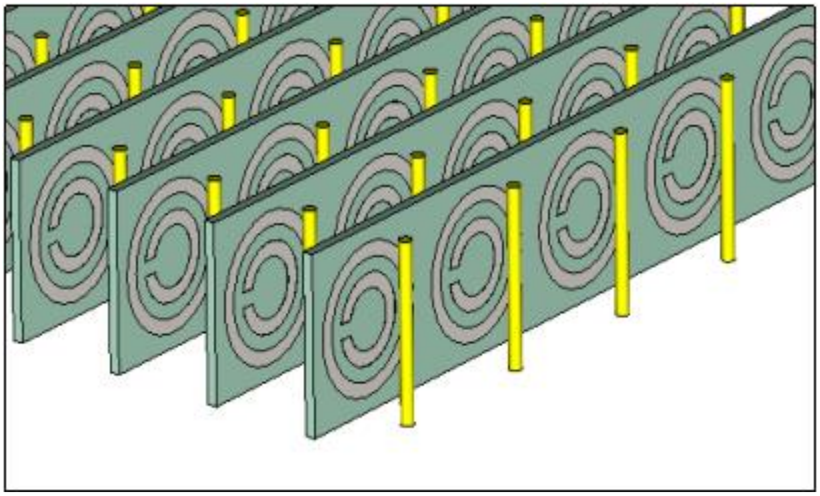


Figure 1.1: First experimental LHM structure

Since its inception twelve years ago, LHM has attracted the attention of numerous researchers, and a number of them have used it to improve the properties of microwave devices like antennas and filters. Despite the initial enthusiasm, some people continued to question the value of LHM. Numerous research have been published with analyses of the characteristics of the LHM integrated with antennas. However, the actual use of LHM technology wasn't fully established until quite recently. The focusing effect of LHM has improved the gain and directedness of a low gain antenna (Engheta, 2014) [6].

2.6 Unique Properties of Left-Handed Metamaterials

Negative Refractive Index: It is assumed that traditional materials have a positive refractive index when discussing them. Metamaterials, on the other hand, can be made to have a negative refractive index. However, left-handed meta-material also has a negative refractive index n and negative permittivity and permeability (Ozbay et al., 2017) [10]. Metamaterials have the ability to bend light in previously unobserved ways because of this special property. Reverse Snell's law: Incident light entering left-handed meta-materials from a right-handed medium will experience refraction, in contrast to what is normally observed with two right-handed media. The phenomenon known as the inverse Snells law is one of the many ways that metamaterials may be used in creative ways.

The Snell's law is described as

$$n_1/n_2 = \sin \alpha_2/\sin \alpha_1.$$

where is the incidence angle and is the refraction angle. When mediums I and II are common materials with '1>0 and '2>0, respectively, refracted light will be bent with a positive angle to the normal line OO', as shown by the fourth light ray in figure 1.2. The refracted light will, however, be bent with a negative angle and in the opposite direction when a right-handed material (2>0) and a left-handed meta-material (with 10) are joined, as shown below. If medium II is a left-handed meta-material with '20, as is shown by the third light ray in figure 1.2, the refracted light will be twisted weirdly with a negative angle with OO' (Zulkifli, 2016)[15].

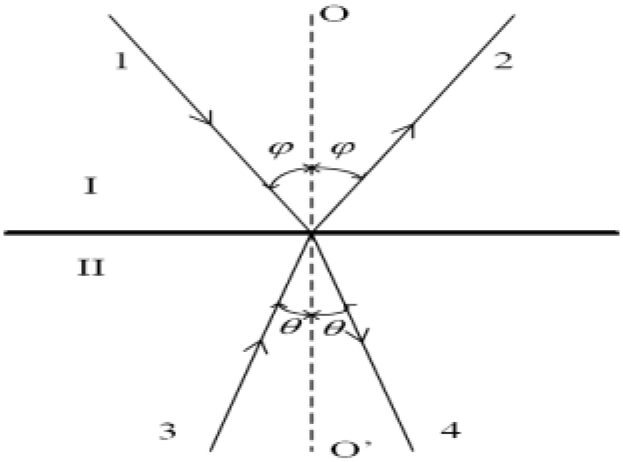


Figure 1.2: Passage of a light ray through the boundary between medium I with positive refractive index and medium II with refractive index

The relationship between the phase velocity and the index of refraction is shown by the phase velocity formula, where c denotes the speed of light in a vacuum. As a result, when a left-handed meta-material and a right-handed material are joined, the combined substance has a negative phase velocity, which causes the refracted light to be bent unexpectedly. When the LHM's refractive index is negative, the phase velocity is also negative (Zulkifli, 2016) [14]. Because of the use of metamaterials in antennas, engineers have been able to produce lighter, more compact, and more efficient antenna structures. The phase velocity in LHM is the polar opposite of the energy flow because the energy flow leaves the source in waves with a phase velocity pointing backward, as seen in figure 1.3. This property of the left-handed material has been used to increase antenna gain and efficiency.

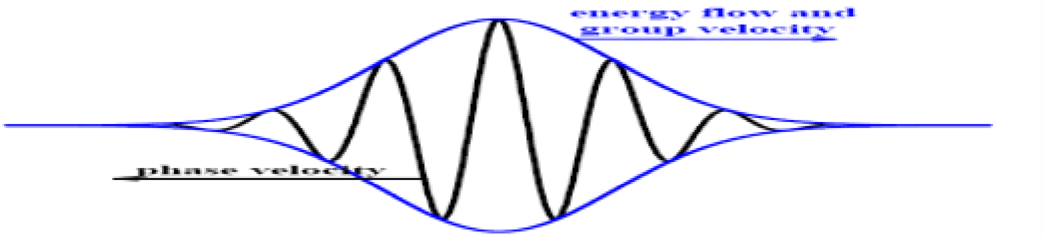


Figure 1.3: The energy flow and group velocity propagate forward in LHMs but the phase velocity is backward

Veselago predicted that the Doppler and Cerenkov effects would be reversed in LHM. In reality, experiments using metamaterials have demonstrated the veracity of this prediction. An approaching source will appear to radiate at a lower frequency because charged particles moving faster than the speed of light in the medium will radiate in a backward cone as opposed to a forward cone. When a left-handed item is placed in front of an observer and an electromagnetic energy source, the Doppler reversal phenomenon occurs. Although these two uncommon traits are not used in this dissertation, information about them is provided there (Zulkifli, 2016)[14]. It follows that it is not surprising that since the publication of Veselago's paper, academics have shown a great deal of interest in these two distinctive characteristics of LHM.

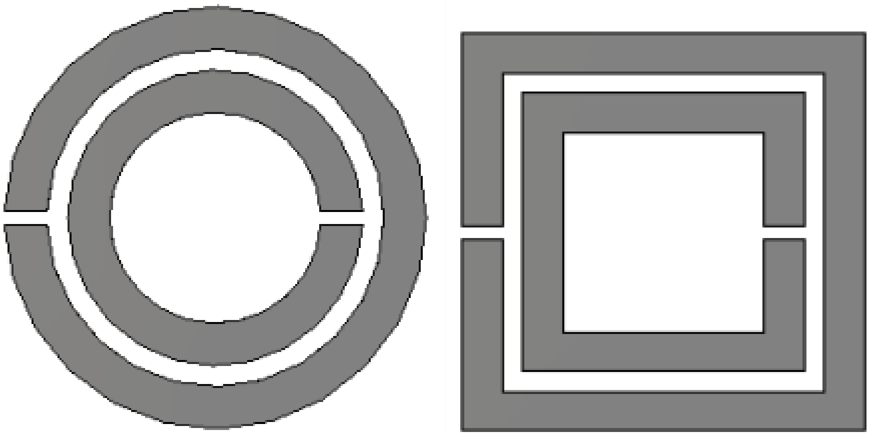
2.7 Metamaterials as Part of Antenna Structure

Metamaterials can be incorporated into the antenna structure to build a compact antenna without compromising performance. It is proposed in this dissertation to employ metamaterials to build an antenna structure that can be scaled down without compromising performance. In this case, patch antennas with high permeability values ($\mu >> 1$) are made using the metamaterials as a magneto-dielectric (MD) substrate. As a result, the antennas size can be significantly reduced without needing a high permittivity ($\varepsilon >> 1$). By utilizing metamaterials, the antenna structure's performance can be improved while its size is decreased. Additionally, as part of the antenna, the metamaterials are given the left-handed transmission line (LH-TL) properties that are often present in a dipole antenna (SANTALUNAI, 2022) [11].

2.8 Left-Handed Metamaterial Structure

The initial LHM construction consists of a split ring resonator (SRR) and a thin wire (TW) or capacitance-loaded strip (CLS). With the combination of SRR, TW, and CLS, LHM integration with antennas is now feasible. The SRR exhibits negative permeability in a particular frequency range, whereas the CLS and TW exhibit negative permittivity. The SRR, TW, and CLS components are combined in LHM structures to control the radiation pattern of an antenna across a wide frequency range (Cahyadi et al., 2021) [3].

Split Ring Resonator (SRR)



(a) (b)

Figure 1.4: (a) Circular split ring resonator and (b) Square split ring resonator

The split ring resonator (SRR), a part of the LHM structure with a negative permeability value, is shown in Figure 1.4. If the magnetic field is excited perpendicular to the structure's plane, a magnetic dipole moment will result. The triangle wedge and the circular loop structure are further elements of the LHM structures that have a negative permittivity value. The SRR's inductance is balanced by the capacitance between its two highly conductive rings. The SRR works as both a resonator and an LC circuit, a device that may store energy in the form of an electric or magnetic field. The SRR induces a structure with a high current density, and this structure has a large magnetic moment.

Capacitance Loaded Strip (CLS) and Thin Wire (TW)

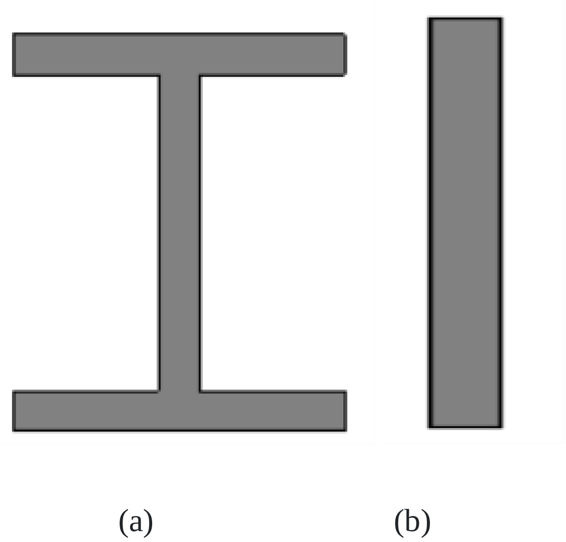


Figure 1.5: (a) Capacitance loaded strip (CLS) and (b) Thin wire (TW)

Figure 1.5(a) shows the thin wire (TW), while Figure 3.5 shows the capacitance-loaded strip (CLS) (b). The CLS has a higher quality factor than the TW due to its higher inductance and capacitance. CLS and TW would exhibit a strong, dielectric-like response. The electric field will produce a current as it passes parallel through the TW or CLS. This reaction and the high current density structure produce a powerful magnetic moment. The result will be a plasmonic-type permittivity frequency and an electric dipole moment in the structure (Cahyadi et al., 2021)[3].

2.9 Metamaterial Applications in Antenna Engineering

In 2006, a left-handed substance was placed between a laser source and an observer to confirm the Doppler reversal effect. Antenna engineering is one of the most important aspects of wireless communication, and it is in this field that frequency-independent antennas and cloaking devices were first used. Due to their incredible ability to change electromagnetic wave polarization, phase, and strength. Metamaterials are made up of a variety of different elements that combine to achieve the desired result. Applications of metamaterials in antenna engineering bring up a world of possibilities for wireless communication systems (Goswami & Karia, 2020)[7].

Metamaterials have revolutionized antenna engineering because of their ability to alter and control the properties of microwaves and radio frequencies. Metamaterials can also be utilized to build the antenna or as part of the feeding mechanism for the antenna system. By positioning HISs or AMCs next to the antenna radiating elements, they are used to build small, low-profile antenna systems. Subwavelength structures that make up metamaterials interact with incident electromagnetic fields to create the required antenna properties. These are frequently very small loops and dipoles (Christodoulides & Feresidis, 2021)[5].

2.10 CST SOFTWARE

In 1992, Thomas Weiland founded CST. The CST Studio Suite, the company's flagship product, is made up of a number of modules that are each focused on a different application area. It will be able to build varied materials with distinct permittivity frequency responses thanks to this electric dipole moment's impact on the material's frequency response. The CST MICROWAVE STUDIO contains modules for RF and microwave applications. Other modules cover low frequency, PCBs and packages and the simulation. The CST Studio Suite is used by many different industries for a range of tasks, including the modeling of electromagnetic interference (EMI) and compliance with numerous global regulatory standards. Each module includes an integrated system and circuit simulator (CST DESIGN STUDIO).

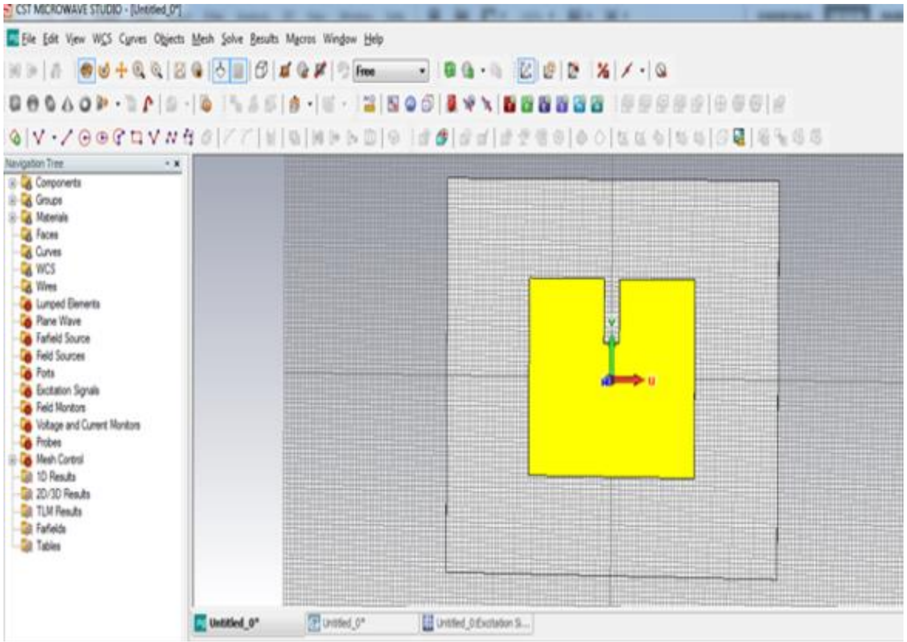


Figure 1.6: CST Microwave Studio

The steps for modeling the LHM with CST software are detailed in depth in the next chapter, along with the LHM's design. Metamaterial structures and patch microstrip antenna design is also created.

CST Microwave Studio is a comprehensive software suite for electromagnetic analysis and design in the high frequency range. CST Microwave Studio can help researchers and engineers better understand and utilize the Doppler reversal phenomena. With the outstanding precision and efficiency of the CST software, patch microstrip antennas, metamaterial structures, electromagnetic systems, and circuits may all be created and analyzed. antennas, extremely effective and accurate patch microstrip antennas, and electromagnetic circuits. The definition of these device is streamlined by strong graphic feedback. CST Microwave Studio is an excellent tool for rapid prototyping and cost-effective design.CST Microwave Studio offers powerful postprocessing tools so the user may view and analyze the detailed findings after the simulation is finished. The Perfect Boundary Approximation (PBA) method and its Thin Sheet Technique (TST) extension improve the simulation accuracy by an order of magnitude above conventional simulators. These two features, along with the automatic meshing procedure, make CST Microwave Studio one of the most reliable simulation tools on the market. The program comprises four unique simulation approaches that are most appropriate for the applications they are utilized in because no methodology performs equally well across all application areas.

Because it can extract the entire broadband frequency behavior of the simulated device from a single calculation run, the transient solver is the tool with the greatest degree of adaptability. Thanks to the combination of these numerous simulation methodologies, the PBA, and TST procedures. This solver works well for the majority of high frequency applications, such as connectors, transmission lines, filters, antennas, and many more (Cao et al., 2017)[4].

CHAPTER 3

The Effects of Applying Metamaterials in Antenna Design

Antennas can be built using metamaterials that are more compact, have greater gains, have wider bandwidths, or are multiband. Depending on the technical requirements of the intended antenna, the metamaterials will be used for various antenna functions. For example, it could be used to modify polarization, enhance directivity, match impedance, or reduce side-lobes.

3.1 The metamaterials in improving gain of antennas

Low gain is the main limitation of small planar antennas, which needs to be addressed to satisfy the whole energy budget of the transceiver system. To boost gain, the antenna can be loaded with metamaterials, which operate to increase the effective permittivity of the antenna construction. Recently, array antennas have been replaced by the metamaterial in the design of antennas. Metamaterials have been used to create artificial structures that can enhance the performance of an antenna.

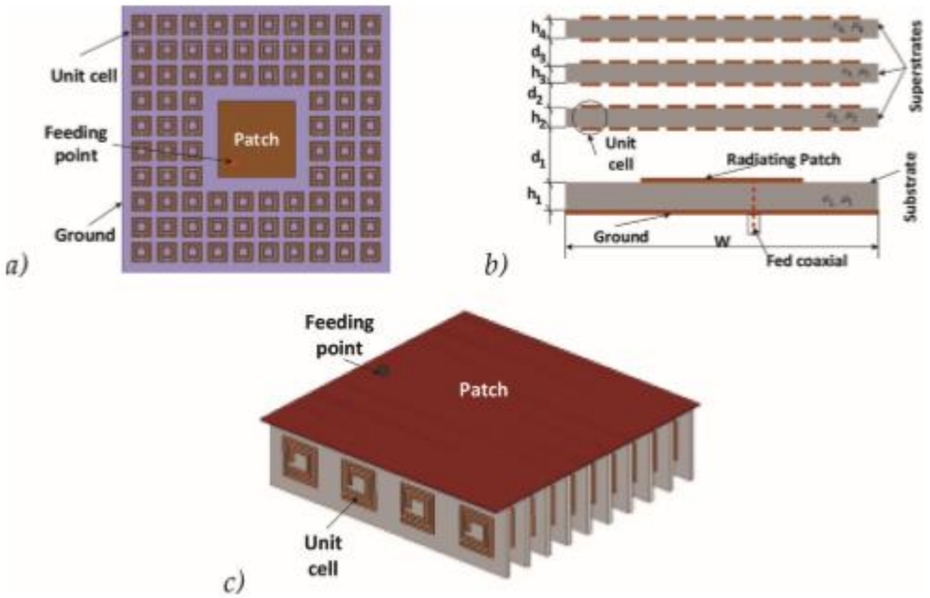


Figure 2.1: Models of metamaterials application in improving the power gain of the antennas: (a) Unit cells surrounding the radiated patch, (b) Metamaterials as superstrate, (c) Using the metamaterials as antenna loading.

3.2 The metamaterials in reducing the size of antennas

Small antennas have been built using fractal geometry, the high-permittivity dielectric substrate of microstrip antennas, shorting pins, and walls, adding some disturbances into the antenna structure, and other technological methods. But one of the most frequently applied repairs is to load the antenna with metamaterials. Recently, several designers have reduced the size of the antenna by employing metamaterials as flawed ground structures (DGS). Metamaterials can also be used to increase the antenna's gain, directivity, and impedance bandwidth.

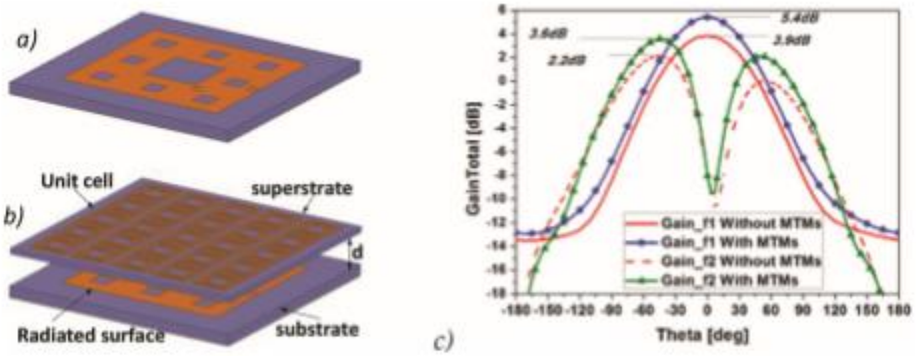


Figure 2.2: (a) The Serpins carpet fractal antenna, (b) The antenna covered with the AMC MTM, and (c) Realized antenna power gain, for two resonant frequencies

3.3 Use of metamaterials to enhance the antenna frequency bandwidth

In addition to the benefits described above, metamaterials are used when building antennas to increase the frequency bandwidth. Since metamaterials rather than conventional ground planes can increase an antenna's bandwidth, this is especially beneficial for broadband applications. To do this, the metamaterials are used as components of an antenna or superstructure positioned above the radiation surface.

3.4 Unit cell of metamaterials

A unit cell or an array made up of numerous unit cells might be the shape of the metamaterials utilized in the antenna design. Therefore, before starting to develop the antenna metamaterials, the key factors affecting the resonance frequency, permittivity, and permeability must be created and examined. Because its unit cell metamaterials are created and tested to take into account the key factors affecting the resonance frequency, permittivity, and permeability of its unit cell. Therefore, once these essential components have been established, it is possible to simulate the performance characteristics of the antenna metamaterials. The operating frequency, size, form, and construction materials of the metamaterials are taken into account to accomplish this. The precise permittivity and permeability values of the metamaterials must also be determined in order to enhance their performance. After the design and modeling of the unit cells is finished, the properties that would be optimal for the antenna metamaterials at a certain operating frequency are found. This process of finding the characteristics needs the use of suitable numerical approaches and optimization tools in order to achieve the desired antenna metamaterials performance. To accommodate resonance frequency requirements, the size of each type of unit cell can be altered. Optimizing the design parameters, such as the size of each unit cell, can lead to the perfect permittivity and permeability values. A unit cell can be less than 1/10 of the operational wavelength depending on the geometry of the metamaterial. Manufacturing accuracy must be considered while developing metamaterials since achieving the necessary performance typically calls for a high degree of precision.

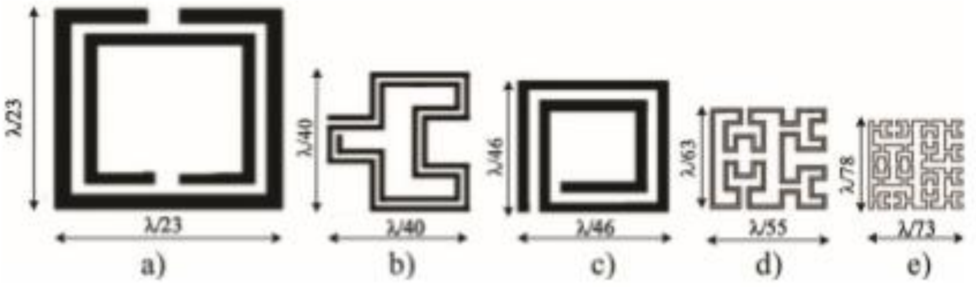


Figure 2.3: A unit cell of an inclusion with the SRR (a), second-order Hilbert fractal inclusion (b), square spiral (c), third order Hilbert fractal inclusion (d), and fourth-order Hilbert fractal inclusion (e). Note that as the order of Hilbert fractal curve increases, the size of inclusion decreases

Calculations show that the expected results are frequently not produced by the numerical simulations of unit cells. Iteratively changing the sizes of the unit cells is necessary to make sure that the simulation results adhere to the requirements of the metamaterial structure. To satisfy simulation findings as rapidly as feasible, it is possible to estimate the size of unit cells using an optimization computational approach. The optimization method in a soft CST program can be used to expedite the procedure and achieve the required results. The unit cell size optimization algorithm is depicted in Figure.

To speed up processing and lighten the load on the computer, the parameter values should be chosen in two steps. We should select start, end and step values in the first stage that are not unduly close to the calculated number. Following optimization, we select the desired outcomes (if achieved). To ensure that the desired performance is attained, manufacturing accuracy must be taken into account while developing metamaterials. Choosing the ideal parameters that provide a result that is the most similar to the intended outcome allows us to continue the optimization process if the results are unsatisfactory. The next step is to choose the start value, which should be close to the value selected in the earlier optimization but less than the value from the previous. phase. The optimal execution will result in the most satisfying results.

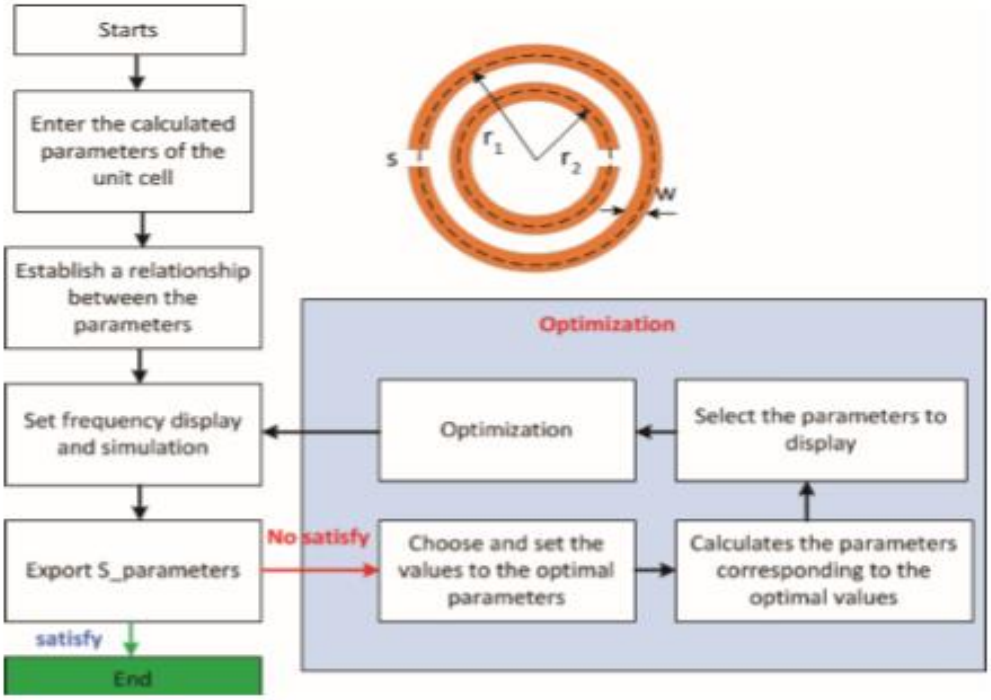


Figure 2.4: Optimal algorithm in designing unit cells of metamaterial

CHAPTER 4

Antenna Design and Analysis

4.1 Simulation

Figure 3.1 shows that the antennas are built without metamaterials and the figure 3.2 shows that antennas are built with metamaterials.

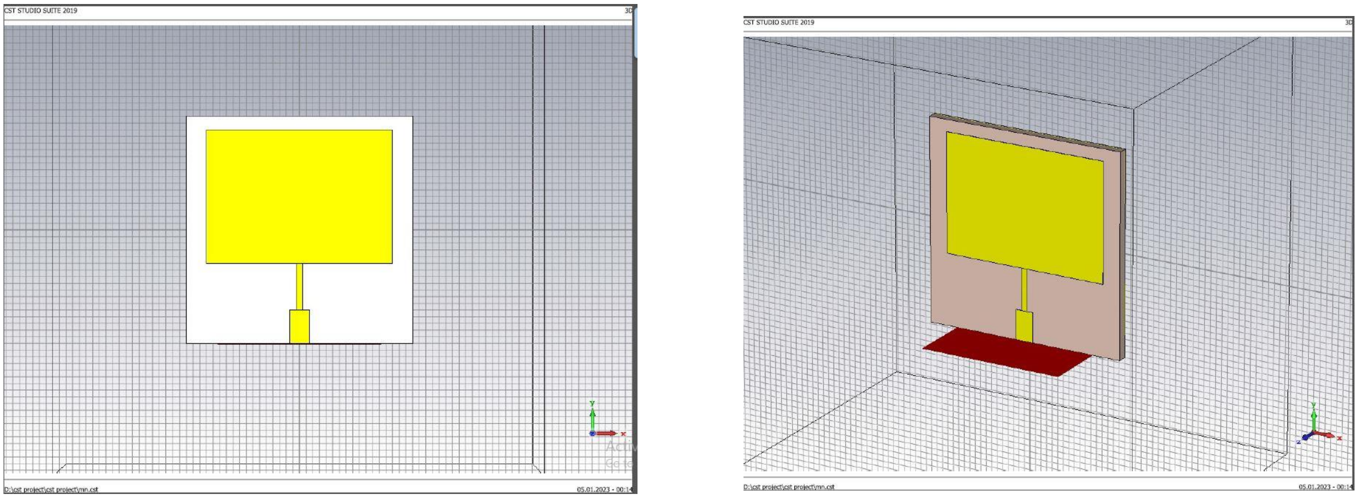


Figure 3.1: Without MTMs

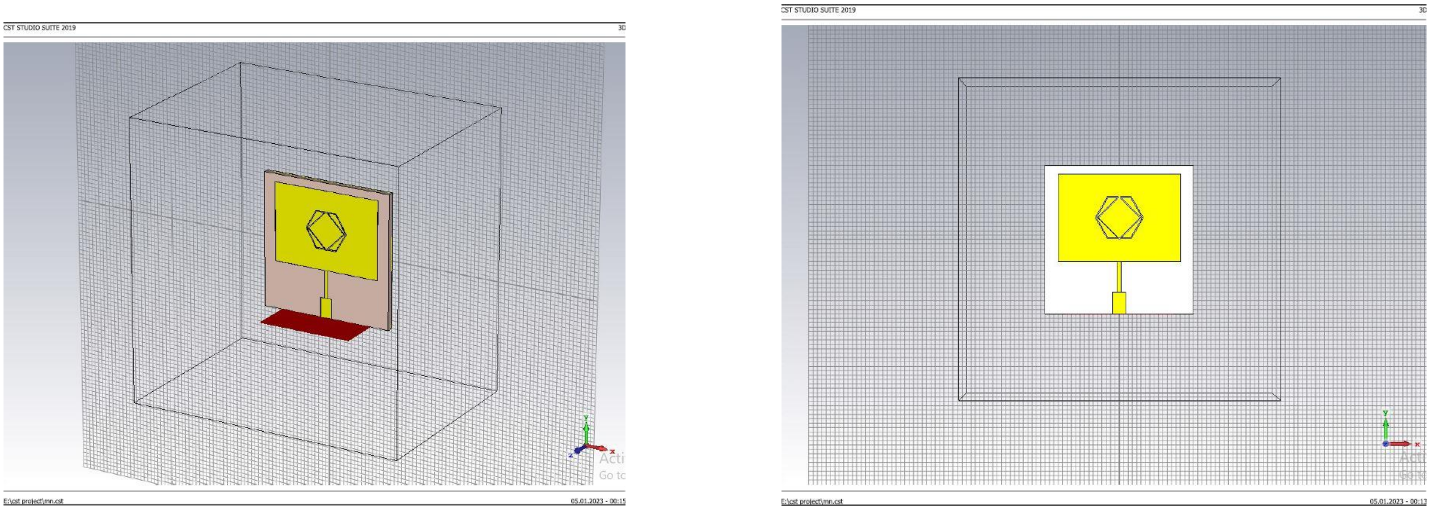
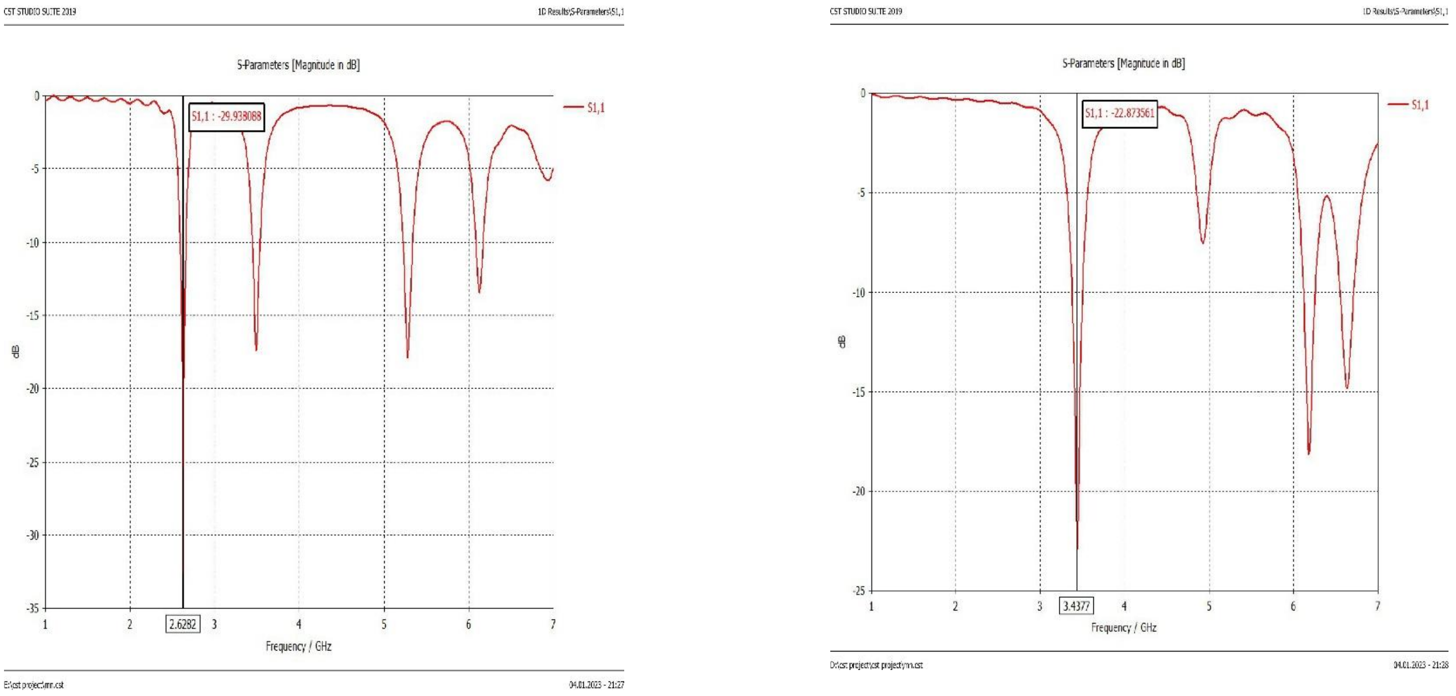


Figure 3.2: With MTMs

4.2 Use of metamaterials to enhance the antenna frequency bandwidth



(a)with MTMs **(b)Without MTMs**

Figure 3.3: S-parameters of antennas without and with MTMs. As (a) With MTMs (b) Without MTMs**.**

Table 1: Comparison between parameters of two types of antennas for WLAN system.

Antenna types	Antenna size ratio, %	Ratio of BW, %	Type of radiation pattern
Without MTM	100	100	Directional
With MTMs	78.7	141	Directional

Depending on the situation, utilizing MTMs as the antenna's DGS can increase bandwidth while reducing antenna size. The features of the metamaterials must be altered throughout the design process in order to ensure that the desired performance is reached. Figure 19 compares two WLAN antennas diameters and bandwidths at the same 2.413 GHz resonance frequency before and after employing MTMs. This comparison makes it clear that using metamaterials results in a smaller antenna and a wider bandwidth. Table 1 shows the ratio of the increased bandwidth to the smaller size. The usage of metamaterials in antenna design has extended the antennas bandwidth. Based on the technical requirements of the intended antenna, the different metamaterial structures and application techniques are selected to construct the optimal antenna. This comparison demonstrates that a smaller antenna and a broader bandwidth are obtained when utilizing metamaterials. Table 1 displays the enhanced bandwidth to lower size ratio. The bandwidth of the antenna has been increased because to the use of metamaterials in antenna design. This comparison demonstrates how metamaterials may be used to generate the desired performance, such as a wider bandwidth and a lower overall size, in antenna designs. The usage of metamaterials in antenna design has extended the antennas bandwidth. Based on the technical requirements of the intended antenna, a variety of metamaterial structures and application procedures are used to provide the optimal antenna bandwidth.

CHAPTER 5

Thesis Management

5.1 Milestone

Milestones of using Metamaterials exhibit qualitatively new electromagnetic response functions that cannot be found in the nature. The use of metamaterials in antenna design not only dramatically reduces the size of the antenna but can also improve other antenna parameters such as enhancing bandwidth, increasing gain, or generating multiband frequencies of antennas operation.

5.2 Lesson learned

Increase bandwidth antenna

The thickness of a substrate with a low dielectric constant, probe feeding, the creation of slots or notches, or the use of varied antenna designs are a few techniques that may be used to expand the bandwidth of an antenna. Aside from these methods, merging numerous antennas into a single system, using multiple-feed systems, and adding active components like amplifiers can also increase an antenna's bandwidth

Metamaterial antenna work

The metamaterial lens functions as a highly efficient coupler to external radiation in metamaterial antenna systems, focusing radiation into the transmitting and receiving components along or from a microstrip transmission line. It may therefore be used as a keyboard. The bandwidth of an antenna might be increased by systems utilizing metamaterial antennas.

CST software used

CST Studio Suite is a comprehensive 3D EM analysis software tool for designing, analyzing, and improving electromagnetic (EM) components and systems. Using CST Studio Suite, one may effectively design and test metamaterial lenses for a variety of antenna systems. In a single user interface, CST Studio Suite offers electromagnetic field solutions for applications spanning the EM spectrum. As a result, users are able to do several simulations, such as eigenmode, transient, frequency-domain, and time-domain analysis.

For this paper, we have first learned how to use the CST software to design the antenna. After that, we make the basic design and show how it work

Antenna is most difficult to design.

The most demanding requirement for antenna design is a small antenna with high gain and a wide band range.

CHAPTER 6

Impact Assessment of The Thesis

6.1 Economical, Societal and Global Impact:

A negative refractive index or electromagnetic cloaking are examples of properties that may be found in metamaterials, which are artificial substances. Metamaterials, which provide exciting possibilities for antenna designers, can be used to solve the problem of building a small antenna with a wide band range and high gain. Metamaterials are used in the manufacture of radars, antennas, and absorbers, which will drive market expansion. The intricacy and sophistication of antenna designs may be addressed through the use of metamaterials. Metamaterials are used in a number of industries, including the automotive, telecommunications equipment, consumer electronics, and aerospace and defense. As metamaterials are utilized more often in these domains, demand for this product will increase. It is estimated that the growing demand for metamaterials would considerably fuel market growth over the course of the anticipated timeframe. Metamaterials will become more and more in demand on the global market as a result of the development of 5G networks and the rising use of 5G technology. The usage of metamaterials in aerospace and defense is predicted to be the main market driver.

Benefits

It is aware that despite the explanation, It will still be curious about the function of a metamaterial. Why is it going to be so important? It may change an object's visibility or invisibility at specific wavelengths, to put it simply. This suggests that the use of metamaterials in the aerospace and defense sectors will be essential for radar and optical camouflage.

For instance, based on their wavelength, ultraviolet, infrared, visible light, microwave, etc. are all various types of light. Some wavelengths may be allowed through while others are blocked by metamaterials. If it create a fabric that is transparent to visible wavelengths using metamaterials, It can see what is on the other side of an apple. What if it had the ability to make someone or anything disappear? It may appear as though this idea belongs in a science fiction novel, but it is really very feasible.

However, these wave-dampening effects are not just applicable to visible light but may also be used in the fields of electromagnetic and acoustics (which are undetectable to ultrasound).

Fields of application

Even if it can now see some distortion through the garments, the fact is that the thing they conceal disappears so it can see what's behind. There are now several invisible clothing prototypes that may be purchased by the general public. This phenomenon, sometimes known as "cloaking" or "invisibility," has been the subject of in-depth study in recent years.

It will see that the most significant developments in this area are now categorized. There is no doubt, however, that they are gradually making their way to market in the form of commonplace items or applications, such as in the deadlock of cars, where the driver would have complete visibility of what is in front of him, lowering the risk of collisions and being run over by pedestrians. Even yet, cloaking has effects that extend beyond the spectrum and range of light.

Additionally, measurements of optical, acoustic, and electromagnetic components may be made with greater precision. With improved cameras, more potent microprocessors, or higher resolution in ultrasound-based medical equipment, among other things, this will surely transform the industry in the near future. Invisibility is the concept of hiding something by scattering light or sound waves around it such that it cannot be seen.**.**

As it have already mentioned, metamaterials are still far from being publicly accessible, but because to their peculiar characteristics, they do demonstrate that the only limit on application development is one's own imagination. Numerous disciplines, including electromagnetism, optics, and acoustics, may benefit from the application of this method. It will closely monitor any developments regarding this sort of material since it believe it will be quite popular in the future. Because metamaterials have the ability to change light in previously unfeasible ways, they are essential for invisibility cloaking.

6.2 Utilization of existing standards of metamaterials

- Metamaterial is frequently employed to modify the elastic properties of materials, absorb electromagnetic radiation, and enhance antenna performance. This makes it a technology with lots of promise that might be used in several areas of daily life. Wide-ranging metamaterials have the potential to advance the study of computer science and medicine, among other fields of study.
- Virtually every sector, but notably clean technology, is being transformed by a brand-new family of materials called metamaterials. With little to no human participation, metamaterials can enhance things that already exist but may have achieved their maximum degree of efficiency. Metamaterials provide a number of advantages beyond enhanced performance. With the use of a completely new technology, we can now tackle industry obstacles.

CHAPTER 7
Conclusions

It can improve on items whose performance was previously assumed to have peaked by using metamaterials, a wonderful resource. The metamaterials might surround the antenna or perhaps make up its whole structure. It can use the tools at its disposal with growing proficiency as technology develops. Designing the unit cells, which are viewed as atoms and give the metamaterial its distinct properties at the desired frequency, is the first step in employing them as an antenna. A wide variety of antenna topologies, including reflect arrays and lens-type antennas, are feasible since the unit cells of the metamaterial were built using electromagnetic theory.

An antenna's power gain, bandwidth, size, and number of frequency bands may all be increased using metamaterials by 2 dB. Metamaterials can also be used to increase the directivity of an antenna. Metamaterials can also be used to create antennas with the proper radiation patterns. Loading metamaterial on or close to the patch and ground plane may be considered a better option for bandwidth augmentation due to its flat design and simplicity. By using metamaterials, it is possible to create antennas with a wide range of desirable properties. Applying a metamaterial superstrate layer to the patch radiator might be one way to achieve high gain at the price of antenna bulk.

In this work, every attempt has been made to include pertinent studies, from the historical development of electromagnetic metamaterial through its use in enhancing antenna performance. However, some important contributions could be missed, and we apologize for accidentally excluding the work of other experts.

REFERENCES

[1] Alam, M.J. *et al.* (no date) *Left-handed metamaterial bandpass filter for GPS, earth exploration-satellite and WiMAX Frequency Sensing Applications*, *PLOS ONE*. Public Library of Science. Available at: https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0224478 (Accessed: January 10, 2023).

[2] B., A. and der Weide, D.W. (2012) “Nonlinear left-handed metamaterials,” *Metamaterial* [Preprint]. Available at: https://doi.org/10.5772/35990.

[3] Cahyadi, C.I., Oka, I.G. and Sitopu, M.W. (2021) “Microstrip antenna design with left handed metamaterial structure for S-band frequency,” *2021 5th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM)* [Preprint]. Available at: https://doi.org/10.1109/elticom53303.2021.9590167.

[4] Cao, T., An, C. and Tian, Y. (2017) “Study on electromagnetic propagation characteristics of two-layer media with CST Software,” *AIP Conference Proceedings* [Preprint]. Available at: https://doi.org/10.1063/1.4992838.

[5] Christodoulides, A. and Feresidis, A. (2021) “Metamaterial substrates for antenna applications,” *2021 Antenna Measurement Techniques Association Symposium (AMTA)* [Preprint]. Available at: https://doi.org/10.23919/amta52830.2021.9620598.

[6] Engheta, N. (2014) *Metamaterials*. 2nd edn. Spie Press.

[7] Goswami, S. and Karia, D.C. (2020) “A metamaterial-inspired circularly polarized antenna for implantable applications,” *Engineering Reports*, 2(10). Available at: https://doi.org/10.1002/eng2.12251.

[8] Innovation, A. (2022) *What are metamaterials? properties, benefits and in which fields can they be used*, *ATRIA Innovation*. Available at: https://www.atriainnovation.com/en/what-are-metamaterials-properties-benefits-and-in-which-fields-can-they-be-used/ (Accessed: January 10, 2023).

[9] Ltd, A.A. (2022) *Literature review on Metamaterial*, *UK Essays*. UK Essays. Available at: https://www.ukessays.com/essays/technology/literature-review-metamaterial-4455.php (Accessed: January 10, 2023).

[10] Ozbay, E., Ozkan, G. and Aydin, K. (2017) “Left-handed metamaterials—a review,” *Oxford Handbooks Online* [Preprint]. Available at: https://doi.org/10.1093/oxfordhb/9780199533046.013.20.

[11] SANTALUNAI, N. (2022) “Investigation on characteristics of metamaterials by using metallic rod structure for Antenna Engineering,” *PRZEGLĄD ELEKTROTECHNICZNY*, 1(5), pp. 105–111. Available at: https://doi.org/10.15199/48.2022.05.19.

[12] Szoplik, T. (2005) *Metamaterials*. 3rd edn. SPIE.

[13] Tatsuo Itoh (2008) “Recent advances in composite right/left-handed metamaterial structures,” *2008 Asia-Pacific Microwave Conference*, 3. Available at: https://doi.org/10.1109/apmc.2008.4958193.

[14] Wikipedia (2022) *History of metamaterials, Wikipedia*. Wikimedia Foundation. Available at: https://en.wikipedia.org/wiki/History_of_metamaterials (Accessed: January 10, 2023).

[15] Zulkifli, F.Y. (2016) “Left-handed metamaterial structure for side lobe suppression of microstrip array antenna,” *KnE Engineering*, 1. Available at: https://doi.org/10.18502/keg.v1i1.518.