"Using Metamaterials for Enhancing Antenna Band frequency"

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.

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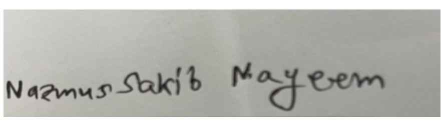
Declaration

I hereby declare that this thesis paper**“Using Metamaterials for Enhancing Antenna Band frequency**” 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. I 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 my obligations and the rights of the participants.



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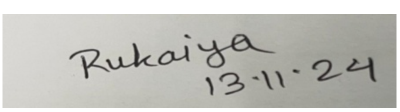
Approval

The Thesis paper entitled **“Using Metamaterials for Enhancing Antenna Band frequency”** submitted by **Nazmus Sakib Nayeem** 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 **November, 2024.**

Signature



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Firstly, I 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.

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Abstract

Metamaterials are metal alloys that possess properties not commonly found in naturally occurring materials. These materials feature unique electromagnetic properties, such as cloaking and a negative refractive index, which are created at the nanoscale. Certain features, such as the ability to bend light or radio waves in a different direction than a standard material, are produced by the materials' peculiar structural structure. Metamaterials have the potential to revolutionize a number of industries, including telecommunications, healthcare, and aerospace. They are frequently employed to alter a variety of energy waves, including light and sound. They are frequently used to modify different energy waves, including light and sound. Therefore, 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. Metamaterials are also being researched for their potential to create invisibility cloaks and superlenses beyond what was previously thought to be possible. Medical imaging, optics, and telecommunications are just a few of the industries that have benefited from metamaterials' previously unimaginable ability to manipulate electromagnetic waves. Researchers are still exploring the vast potential of metamaterials to create revolutionary technologies that could fundamentally change how people interact with and use energy. Because of their variety and adaptability, metamaterials are of special interest to scientists and engineers who wish to push the boundaries of what is feasible in the realm of wave modification and control. Through ongoing research and testing, scientists are discovering new and creative applications for metamaterials, like cloaking devices that may render objects invisible to particular light wavelengths. The use of metamaterials in antenna design has increased directivity, gain, bandwidth, and efficiency.The properties of the metamaterials must be altered during the design stage to ensure that the desired performance is attained. By altering

the properties of the metamaterials, engineers may modify the behavior of waves in ways that have never been possible before. Two WLAN antenna diameters and bandwidths were measured at the same 2.413 GHz resonance frequency before and after the use of MTMs. When it shrinks by 20%, its frequency rises by 40%. lower-quality antenna systems. In many applications, improved functionality and performance result from the precise control of wave behavior made available by the manipulation of metamaterial features. All things considered, using metamaterials in antenna design offers a practical means of maximizing wireless communication system performance. Metamaterials have been widely used in antenna building due to their distinct electromagnetic properties. Electromagnetic metamaterials enable enhanced gain, directivity, bandwidth, and size reduction. The most recent research on using metamaterials to enhance antenna performance has been analyzed and reviewed in this publication.

CHAPTER 1

Introduction

With the growing need for wireless communications and compact, portable devices, designers worldwide are striving to reduce the size of antennas. As a result, engineers are putting a lot of effort into developing components for these gadgets that are more compact and effective. One innovative solution that has emerged is the use of metamaterials, which can manipulate electromagnetic waves in ways that were previously thought impossible. By incorporating these materials into antenna design, engineers are able to create antennas that are smaller and more efficient than ever before. Despite its compact size, it should have great efficiency, broadband operation, and several advantages. Engineers are creating a range of innovative enhanced portability and efficiency in antenna designs than conventional monopoles or dipoles for antennas in order to accomplish these goals.One of the antennas that has attracted the most interest lately is the microstrip patch antenna. An insulating substrate, a transmission wire, and a small piece of conducting material make up this antenna. A few advantages of the microstrip antenna include its low profile, lightweight, compact, conformable design, ease of manufacture, and compatibility with solid-state electronics.This antenna offers key advantages such as a compact design, lightweight construction, and compatibility with other solid-state devices.Nevertheless, microstrip antennas have a significant disadvantage because of their constrained bandwidth. Recently, several methods and research have been done to increase the bandwidth. These techniques ranged from employing a metal patch as the radiating element to including a meander line or an open-circuit stub into the feeding network.

"Metamaterials" are novel materials that have emerged in recent years and are being widely employed in a variety of applications. Metamaterials provide considerable choices for downsizing antennas as well as special electromagnetic features such as a negative index of refraction. These skillfully crafted composite buildings have a few unique qualities that aren't seen in natural materials.Metamaterials were first postulated by Veselago in 1967. They are also known as synthetic materials exhibiting negative permittivity and permeability, double negative (DNG) materials, or left-handed materials (LHM).. Because metamaterials enable previously unimaginable light manipulation, they have revolutionized the disciplines of photonics and optics. Since then, these materials have found utility in a variety of applications, including perfect lenses, cloaking technologies, and sub-wavelength imaging. Thirty-two years after the original publication, in 1999, Pendry and his colleagues revised the data.They demonstrated how metamaterials can be engineered to have exact permittivity and permeability values and how these materials can be used to construct structures with peculiar characteristics. Because it demonstrated how to make and use metamaterials to acquire qualities not seen in nature, this study was essential to the development of metamaterials. They concluded that different metallic wires and split ring resonators may be used to achieve negative permittivity and negative permeability, respectively.

Smith and his associates used thin wire and a split ring resonator to produce a construction in 2001 in response to this understanding.Smith and his colleagues organized this arrangement in 2001. Right now, metamaterials are becoming more and more popular. Because of its negative permeability and permittivity, it is the first example of a metamaterial with extraordinary propertiesThe work of Smith et al. (2001) allowed for the synthesis of new materials with properties not seen in nature.

CHAPTER 2

Literature Review

2.1 Introduction

A literature review is a comprehensive summary of past research on a certain topic. It offers a thorough review of the state of the field's knowledge, emphasizing important discoveries, research approaches, and knowledge gaps.A review of the literature examines academic journals, publications, and other materials that are relevant to a particular field of study The review of the literature's objective is to position the work in context, assess the current level of knowledge on a subject, and identify knowledge gaps. In addition to helping identify any conflicting information or past research on the topic, it should offer a theoretical foundation for the inquiry.

2.2Metamaterials

An appealing substitute that has been created to get around the drawbacks of conventional antennas is metamaterials. Metamaterials have unique properties that allow them to manipulate electromagnetic waves in ways that traditional materials are unable to. It has been applied in a variety of diverse domains, including electromagnetics, physics, and material science. [8] 2022 Innovation.

2.3The Left-Handed Metamaterial

Reverse waves and negative refraction are two of the Left-Handed Metamaterial's (LHM) special qualities (Alam et al.)[1]. This chapter covers a number of applications involving LHM antennas and the basic ideas that underpin their special qualities.

2.4Background of Left-Handed Metamaterial

Left-handed materials, or LHMs for short, are a broad class of metamaterials that have A negative index of refraction and reverse wave propagation (Ltd, 2022).. These unique properties enable applications in cloaking devices, lens design, and other advanced technologies. Metamaterials that are electromagnetic and have negative permeability and permittivity (DNG) are known as Both double-negative and left-handed metamaterials (LHM). Since LHMs are artificial materials with unique electromagnetic properties not found in natural materials, they are highly coveted for a range of scientific and technological advancements. Conventional antenna designs cannot provide the wide bandwidth and efficient radiation patterns made feasible by this state-of-the-art technology (Tatsuo Itoh, 2008)[13].

2.5 Left-Handed Metamaterial LHM (HISTORY)

The initial study of LHM was initiated by V. G. Veselago of the Lebedev Physical Institute in Moscow, who speculated about the negative permittivity and permeability of this synthetic materialThe presence of this material, according to Veselago, might cause a phenomena called negative refraction, which could result in ground-breaking advancements in a variety of fields, such as optics, telecommunications, and imaging. (Wikipedia, 2022). Since then, the scientific community throughout the world has given this concept a lot of thought and research. When entering the medium, a wave is twisted in the opposite direction of its usual journey (14). The left-handed drug concept gained popularity. The first experimental verification was carried out by Shelby, Smith, and Schultz at the University of California after this intriguing discovery in 2001 (Szoplik, 2005) [12]. They demonstrated the viability of Veselago's concept by using a material that had a periodic structure of copper wires and split-ring resonators and was able to absorb electromagnetic radiation. Figure 1.1 illustrates how a thin wire and a split ring resonator reflect the material structure is left-handed.

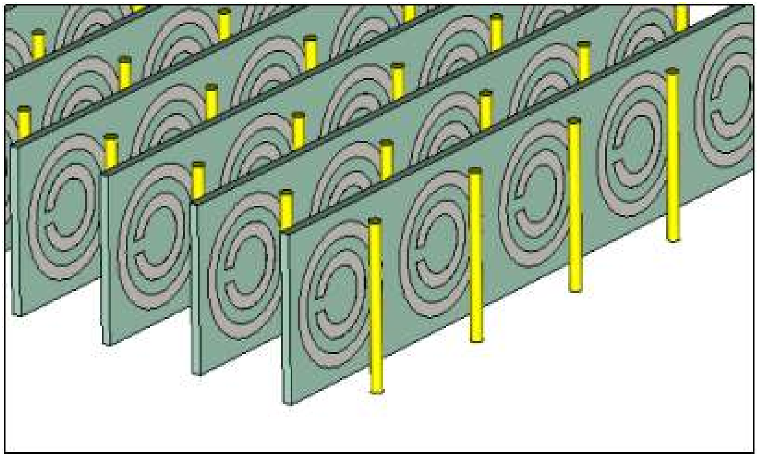


Figure 1.1: First experimental LHM structure

Twelve years after its launch, LHM has attracted the attention of many researchers, some of whom have used it to improve the characteristics of microwave devices like antennas and filters. These researchers found that LHM can improve the performance of these gadgets by altering electromagnetic waves in new ways. Even with the initial fervor, several people remained skeptical of LHM's worth. However, as more research is conducted and results are published, the potential benefits of using LHM in microwave devices become more apparent. The features of the LHM in combination with antennas have been analyzed in a number of academic publications. But it wasn't until lately that LHM technology was actually put to full use. The low-gain antenna's directedness and gain have been enhanced by the LHM's focusing effect(Engheta, 2014) [6].

2.6Unique Properties of Left-Handed Metamaterials

Refractive Index Negative: When talking about traditional materials, it is presumed that they have a refractive index that is positive. However, metamaterials can be engineered to have a refractive index that is negative. Yet, according to Ozbay et al. (2017) [10],Left-handed metamaterials exhibit a negative refractive index, along with unique properties of permeability and permittivity. These unconventional traits allow them to manipulate light in ways that traditional materials cannot. One of the most striking effects is the inversion of Snell's law: when light transitions from a right-handed medium into a left-handed metamaterial, it refracts in the opposite direction from what we typically expect. This "inverse Snell's law" phenomenon represents a creative and groundbreaking application of metamaterials, enabling new possibilities for controlling light and electromagnetic waves in novel ways.
Snell's law is described as

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

There are the angles of events and refraction? The angle formed by the incident ray and the surface normal is known as the incidence angle, and the angle formed by the refracted ray and the normal is known as the refraction angle. The fourth light ray in figure 1.2 illustrates how Light that is refracted will be bent with a positive angle to the normal line OO' when mediums I and II are common materials with '1>0' and '2>0, respectively. This bending happens because light changes its speed when it moves through different materials, changing the light ray's direction. However, as seen below will cause the refracted light to bend in the opposite direction and at a negative angle when a, left-handed meta-material (with 10) and a right-handed material (2>0) are joined. This effect, known as negative refraction, is brought on by the characteristics of the materials involved. The third light beam in figure 1.2 (Zulkifli, 2016)[15] indicates that if medium II is a left-handed meta-material with '20, the refracted light will be twisted weirdly with a negative angle with OO'.

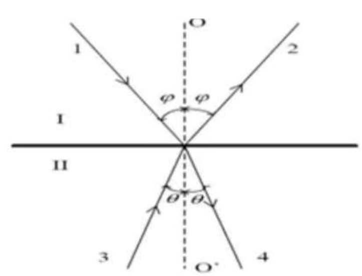


Figure 1.2: movement of a light ray between medium I, which has a positive index, and medium II over the refractive index barrier.

The phase velocity formula, where c is the speed of light in a vacuum, illustrates the connection between the phase velocity and the index of refraction. This method is widely used in optics to calculate the speed at which a wave moves through a medium. An unexpected bending of the refracted light results from the coupling of a left-handed meta-material with a right-handed material, which has a negative phase velocity. This phenomenon, known as negative refraction, has important implications for the development of new optical systems.Phase velocity is negative when the refractive index of the LHM is negative (Zulkifli, 2016) [14].Engineers are now able to create antenna structures that are more compact, lightweight, and efficient thanks to the usage of metamaterials. Metamaterials have also been utilized to construct superlenses because, as shown in figure 1.3, the energy flow exits the source in waves with a phase velocity pointing backwards. In LHM, the energy flow is exactly the opposite of the phase velocity. Antenna efficiency and gain have been increased by utilizing the left-handed material's characteristic.

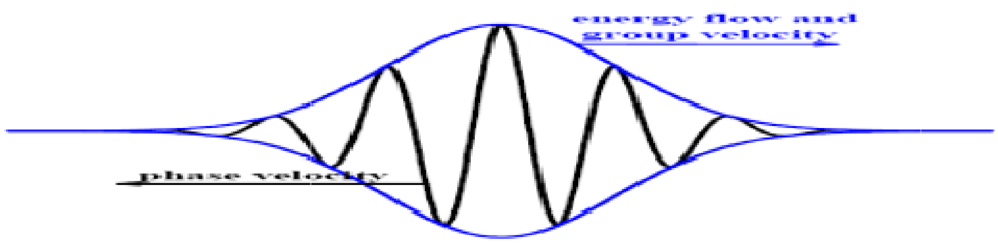


Figure 1.3: The energy flow and group velocity propagate forward in LHMs but the phase velocity is backward.

According to The Doppler and Cerenkov effects, Veselago, would be inverted in LHM. Metamaterials experiments have shown that this prediction is accurate. Because charged particles traveling through the medium faster than the speed of light will radiate in a cone that is backwards instead of forwards, an approaching source will appear to radiate at a lower frequency. The Doppler reversal phenomenon happens when a left-handed object is positioned facing a source of electromagnetic radiation and an observer. Although not discussed in this dissertation, there is information regarding these two unusual qualities available there (Zulkifli, 2016)[14].Thus, it should come as no surprise that scholars have become quite interested in these two unique aspects of LHM since the release of Veselago's study.

2.7Metamaterials as Part of Antenna Structure

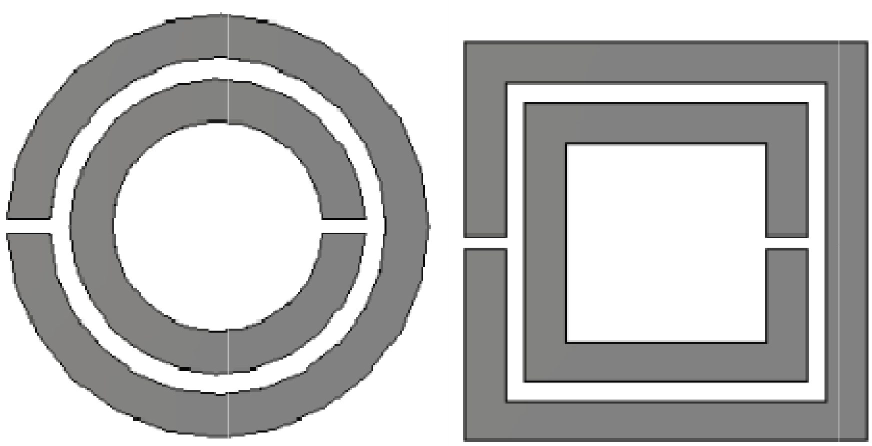
Performance may be maintained while producing a small antenna by integrating metamaterials into the antenna structure. Metamaterials can be manufactured in novel ways to modify electromagnetic waves, enabling small and efficient antenna designs. According to this dissertation, metamaterials can be used to create an antenna construction that is smaller without sacrificing functionality. Because it uses metamaterials to produce great performance in a reduced form factor, the antenna is ideal for applications with limited space. Here, the metamaterials are used as a magneto-dielectric (MD) substrate to create patch antennas with high permeability values ($\mu >> 1$).As a result, a considerable reduction in antenna size is possible without having a large permittivity ($\varepsilon >> 1$). When the antenna structure's size is reduced, its performance can be enhanced by using metamaterials. Increased effectiveness and adaptability are made possible by this innovative approach in a variety of applications, especially those with constrained space. Furthermorethe left-handed transmission line (LH-TL) is applied to the metamaterials characteristics often seen in a dipole antenna in order to function as an antenna component.

2.8 Left-Handed Metamaterial Structure

A capacitance-loaded strip (CLS) or thin wire (TW) in conjunction with a split ring resonator (SRR) make up the original LHM architectureThe integration of LHM with antennas has become possible thanks to the combination of SRR, TW, and CLS. While the SRR shows negative permeability within a specific frequency band

For CLS and TW, permittivity is not positive. LHM structures integrate the SRR, TW, and CLS components to regulate an antenna's emission pattern across an extensive frequency spectrum .

Split Ring Resonator (SRR)

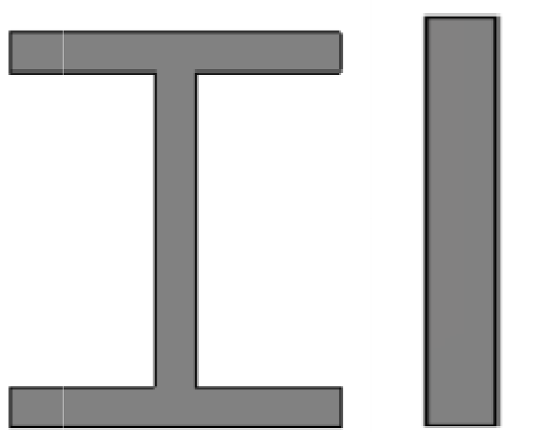


(a) (b)

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

Figure 1.4 displays the split ring resonator (SRR), a component of the LHM architecture with a negative permeability value. The SRR is often used in metamaterials to achieve unique electromagnetic properties such as negative refraction. A magnetic dipole moment will occur if the magnetic field is stimulated perpendicular to the plane of the structure. Two further LHM structures with negative permittivity values are the triangle wedge and the circular loop structure. These structures are also necessary for manipulating anomalous electromagnetic waves. The capacitance between the two highly conductive rings of the SRR balances its inductance. The SRR has the ability to store energy as an electric or magnetic field. These properties open up possibilities by making it possible to manipulate electromagnetic waves at subwavelengths. It functions as a resonator as well as an LC circuit. A structure with a large magnetic moment and a high current density is induced by the SRR.

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



(a) (b)

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

Figure 3.5 displays the capacitance-loaded strip (CLS) (b), while Figure 1.5(a) displays the thin wire (TW). Because the CLS has a bigger capacitance and inductance than the TW, it has a better quality factor. CLS and TW would respond with a dielectric-like strength. As the electric field moves through the TW or CLS simultaneously, current will be produced. The structure of high current density and this reaction result in a powerful magnetic moment. An electric dipole moment and a plasmonic-type permittivity frequency will arise from this (Cahyadi et al., 2021)[3].

2.9Metamaterial Applications in Antenna Engineering

In order to verify the Doppler reversal phenomena, a left-handed item was positioned between an observer and a laser source in 2006. Cloaking devices and frequency-independent antennas were initially employed in antenna engineering, one of the most crucial areas of wireless communication, due to their exceptional capacity to alter the polarization, strength, and phase of electromagnetic waves. The intended effect is produced by the combination of several components that make up metamaterials. Wireless communication systems now have several options thanks to the application of metamaterials in antenna engineering (Goswami & Karai, 2020)[7].

The capacity of metamaterials to manipulate and change the characteristics of radio frequencies and microwaves has transformed antenna engineering. The antenna system's feeding mechanism or antenna structure can also make use of metamaterials. By placing AMCs or HISs adjacent to the components that radiate from the antenna, small low-profile antenna systems may be built. The subwavelength structures of The interaction of incoming electromagnetic fields with metamaterials results in generate the required antenna properties. These are frequently minuscule loops and dipoles .

2.10 CST SOFTWARE

Thomas Weiland established CST in 1992. The company's flagship product, the CST Studio Suite, consists of several modules, each specialized in a certain application domain. Because of the effect of the impact of this electric dipole moment on the material's frequency response it will be able to construct a variety of materials with different permittivity frequency responses. Modules for RF and microwave applications are available in the CST MICROWAVE STUDIO. Additional modules address the simulation, PCBs and packages, and low frequency. Numerous sectors use the CST Studio Suite for a variety of purposes, such as electromagnetic interference (EMI) modeling and compliance with multiple international regulatory requirements. An integrated system and circuit simulator are included in every module (CST DESIGN STUDIO).

Figure 1.6:CST Microwave Studio

The next chapter goes into great detail on the LHM's design and how to model it using CST software. Patch microstrip antenna designs and metamaterial structures are also developed.

Engineers and researchers can make greater use of and understanding of the Doppler reversal phenomenon with the aid of CST Microwave Studio. A whole suite of software called CST Microwave Studio is used for high-frequency electromagnetic analysis and design. The CST software's exceptional accuracy and efficiency allow for the creation and analysis of patch microstripantennas, metamaterial structures, electromagnetic systems, and circuits. electromagnetic circuits, antennas, and patch microstrip antennas that are incredibly precise and effective. Robust graphic feedback streamlines the definition of these devices. CST Microwave Studio is a great tool for affordable design and quick prototyping.After the simulation is complete, the user can examine and analyze the comprehensive results with the advanced post processing capabilities provided by CST Microwave Studio. The Thin Sheet Technique (TST) version of the Perfect Boundary Approximation (PBA) technology increases the simulation accuracy by a factor of ten compared to traditional simulators.. No methodology works equally well in all application areas, hence the program consists of four distinct simulation methodologies that are best suited for the applications in which they are used.

The transient solver's ability to recover the whole broadband frequency behavior of the simulated device from a single computation run makes it the most flexible instrument. Because of the integration of the PBA, TST procedures, and various simulation approaches. Most high-frequency applications, including filters, antennas, transmission lines, connections, and many more, function well with this solver.

CHAPTER 3

The Impact of Using Metamaterials in Antenna Architecture

Greater gains, multi-band, compact, and/or multi-band metamaterials larger bandwidths can be used to construct antennas. The metamaterials will be employed for different antenna functions based on the target antenna's technical specifications. It could be applied to match impedance, lessen sidelobes, improve directivity, or adjust polarization, among other things.

3.1 The Use of Metamaterials to Increase Antenna Gain

The primary drawback of compact planar antennas is low gain, which must be overcome in order to meet the transceiver system's entire energy budget. Metamaterials can be added to the antenna to raise its gain by raising the effective permittivity of the antenna's structure. Metamaterial has recently taken the position of array antennas in antenna design. Artificial structures that can improve an antenna's performance have been made using metamaterials.

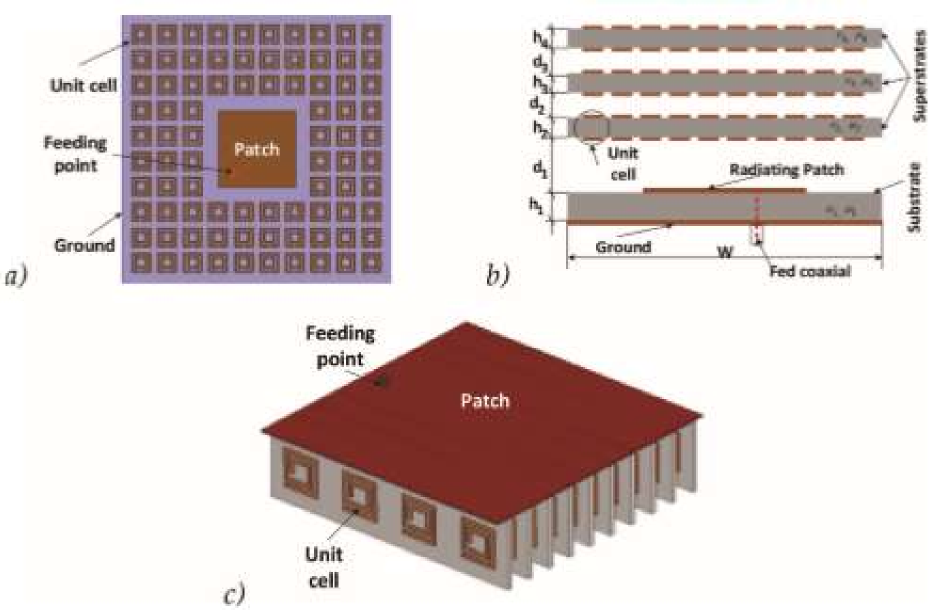


Figure 2.1: Models of metamaterials being used to increase antenna power gain: (a) Unit cells surrounding the radiated patch, (b) Metamaterials as superstrate, (c) Using the metamaterials as antenna loading.

3.2 The metamaterials in reducing the size of antennas

Microstrip antennas' high-permittivity dielectric substrate, or fractal geometry walls, interfering with the antenna construction, shorting pins, and other technical techniques have all been used to build small antennas. However, loading the antenna with metamaterials is one of the most widely used fixes. Recently, a number of designers have used metamaterials as imperfect ground structures (DGS) to shrink the antenna's size. The gain, directivity, and impedance bandwidth of the antenna can all be increased with the usage of metamaterials.

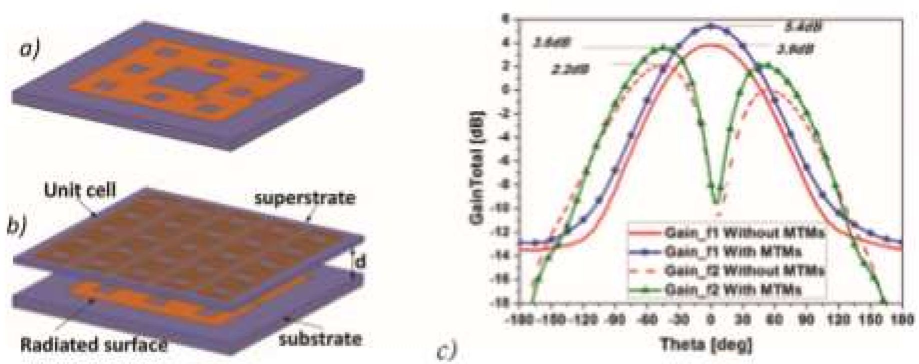


Figure 2.2:(a)The Serpins carpet fractal antenna, (b) The antenna covered with the AMC MTM, and (c) Realized antenna power gain, for two resonant frequencies.

3.3 Use of metamaterials to enhance the antenna band frequency

Utilizing metamaterials to broaden the frequency spectrum of the antenna. Along with the above listed advantages, the usage of metamaterials in antenna construction to expand the frequency bandwidth. Increasing an antenna's bandwidth with metamaterials instead of traditional ground planes is particularly advantageous for broadband applications. The metamaterials are utilized as parts of a superstructure or antenna that is positioned above the radiation surface in order to achieve this.

3.4Unit Cell of Metamaterials

The form of metamaterials used in the antenna design may consist of an array or a unit cell composed of many unit cells. Finding and researching the main variables affecting the resonance frequency, permittivity, and permeability is therefore essential before beginning to build the antenna metamaterials. Because when it develops and tests its metamaterials, it considers the primary elements that determine the resonance frequency of its unit cell, namely permittivity and permeability. Thus, it is possible to replicate the antenna metamaterials' performance characteristics once these crucial elements have been determined.

To achieve this, consideration is given to the size, form, construction materials, and operating frequency of the metamaterials. To improve the performance of the metamaterials, the exact permittivity and permeability values must also be ascertained. For identifying the features and obtain the desired antenna metamaterial performance, the right computational techniques and optimization tools must be used. The optimal parameters for the antenna metamaterials for a particular operating frequency are established when the unit cell design and modeling are finished.

Each sort of unit cell can have its size changed to meet criteria for resonance frequency. To achieve the ideal permittivity and permeability values, The dimensions of each unit cell and other design factors can be optimized.depending on the shape of the metamaterial, a unit cell may be less than 1/10 of the practical wave length. When creating metamaterials, manufacturing accuracy needs to be taken into account because obtaining the required performance usually demands a great deal of accuracy.

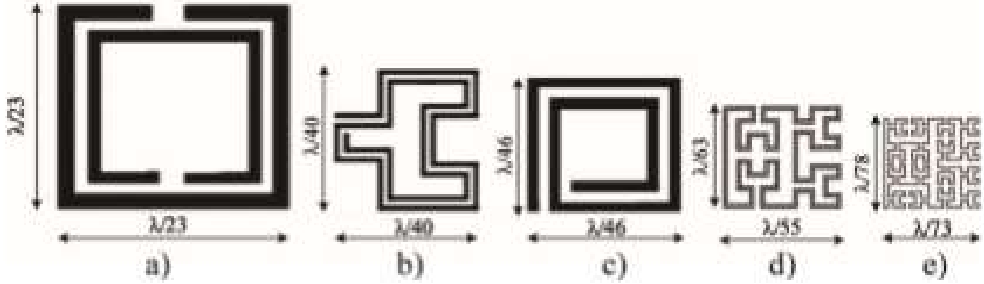


Figure 2.3:A unit cell of inclusion with the SRR (a), second-order Hilbert fractal inclusion (b), square spiral (c), third-order Hilbert fractal inclusion (d), and fourth-order Hilbert fractal inclusion (e). Note that as the order of the Hilbert fractal curve increases, the size of inclusion decreases

The outcomes of numerical simulations of unit cells are generally not what is predicted, according to calculations. The unit cell sizes must be iteratively adjusted to ensure that the simulation results meet the metamaterial structural requirements. In order to meet simulation findings as quickly as possible, the size of unit cells might be determined using an optimization computational approach. A soft CST program's optimization technique can be applied to speed up the rules for getting the desired outcomes. The algorithm for optimizing unit cell size is depicted in the figure.

The parameter values should be selected in two stages to expedite processing and reduce the strain on the computer. In the first step, we should choose start, finish, and step values that are not too near to the estimated value. After optimization, we choose the intended results (if attained). When developing metamaterials, manufacturing accuracy needs to be considered to guarantee that the desired performance is achieved. If the results are inadequate, we can continue the optimization process by choosing the optimal parameters that yield a result that is closest to the desired output.Selecting the start value is the next stage; it should be smaller than the value from the previous phase but closer to the value chosen in the earlier optimization. The most palatable outcomes will come from the finest possible execution.

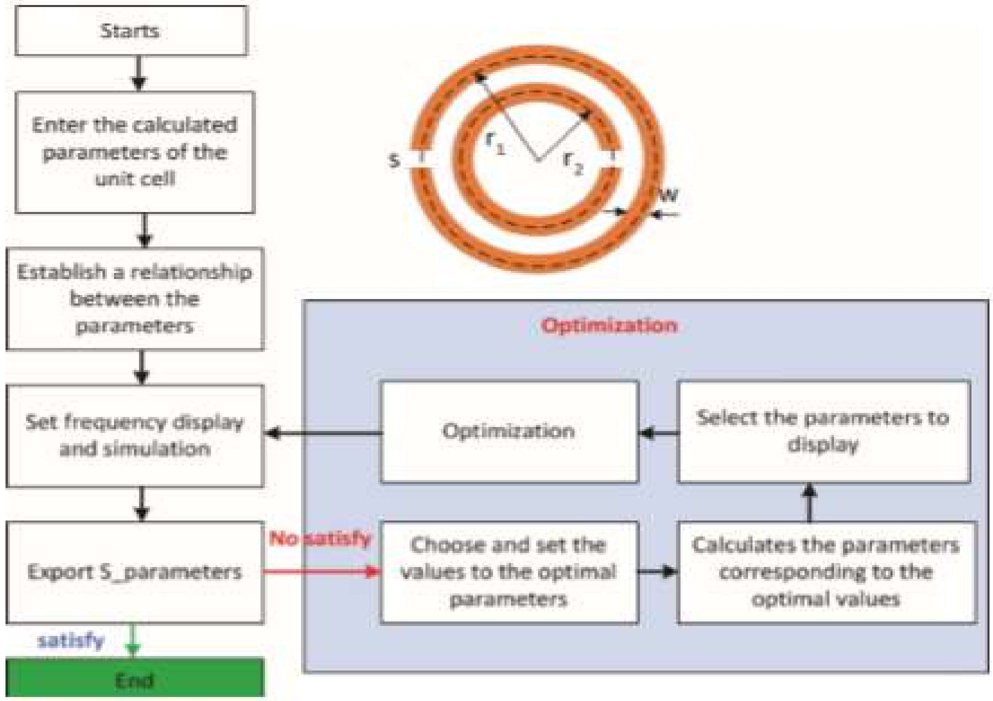


Figure 2.4: Optimal algorithm in designing unit cells of metamaterial

CHAPTER 4

Design and Analysis of Antenna

4.1 Design Selection

4.1.1 Purpose ofMetamaterials for Antenna Design.

A synthetic material characterized by properties absent from natural materials is referred to as a metamaterial. Among the primary features of metamaterials is their ability to regulate electromagnetic waves in ways that are difficult or impossible to do with conventional materials.

Antennas are used to transmit and receive electromagnetic waves, and their efficiency is vital in a variety of applications such as radar, satellite communications, and telecommunications.

4.1.2 Selection& Specifications

The following elements are taken into account while selecting metamaterials for a particular application:

1. Range of frequencies:
2. Dielectric constant:
3. Magnetic permeability:
4. Losses:
5. Fabrication:
6. Environmental factors:

While choosing metamaterials for a particular application, it is important to carefully consider these and other factors in order to get the desired performance characteristics.

4.1.3 Reason to use Left-Handed Materials

Left-handed metamaterial, or LHM, is one type of metamaterial that has a negative refractive index. This suggests that, contrary to what one might expect from a natural substance, they have the capacity to bend electromagnetic waves in diverse directions. LHM has the potential to enhance antenna performance in several ways, such as:

1. Miniaturization
2. Bandwidth
3. Directivity
4. Polarization

All things considered, their use in antenna design can lead to more effective, small, and flexible antenna systems—all of which are necessary for many modern technologies.

4.1.4 Copper in Metamaterials

The great electrical conductivity of copper and its compatibility with current production techniques make it a prominent material in metamaterials. Thin films, nanowires, and nanoparticles are just a few of the ways copper may be used in metamaterials. It can also be engineered to give the necessary metamaterial structure.

Copper is very useful when designing metamaterial antennas since it is a great electromagnetic wave conductor, which is required for effective transmission and reception. By using copper to produce metamaterials with negative permittivity, left-handed metamaterials with a negative refractive index may be produced.

Copper may also be used to create metamaterials with a high q-factor, which is a measurement of the resonant frequency response. High-q metamaterials can be used in applications such as filters and sensors where a restricted frequency response is required.

Copper has many advantages over other materials, including low cost and ease of manufacturing using standard microfabrication techniques. Due to this, copper is a material of interest for use in metamaterials in a range of fields, including telecommunications, medical imaging, and radar.

4.1.5 Use of Copper for designing Antenna.

Copper is often used in antenna design because to its strong electrical conductivity and compatibility with existing manufacturing techniques. Copper is commonly used in metamaterial antennas for several reasons, including:

1. Good electrical conductivity: Copper has a high electrical conductivity, which is essential for the effective transmission and reception of electromagnetic waves. This is especially important in antenna design, as the antenna must be able to transmit and receive electromagnetic waves effectively.

2. Compatibility with fabrication techniques: Copper is compatible with photolithography and etching, two common micro fabrication techniques used to create metamaterial structures. This makes utilizing regular processes to fabricate copper metamaterial antennas easier.

3. Low cost: Copper is very inexpensive as compared to other metals, making it an attractive alternative for metamaterial antenna design.

4. 4. Outstanding thermal stability: Copper's remarkable thermal stability allows it to keep its electrical properties even at very high temperatures. This is important for applications that need high-power transmission, such as satellite communications.

5. Versatility: Because copper is easily patterned to create a wide range of metamaterial structures, it is a versatile material for antenna design.

All things considered, due to its excellent electrical conductivity, low cost, robust thermal stability, and suitability for production processes, copper is an ideal material for use in metamaterial antennas.

4.2 Simulation

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

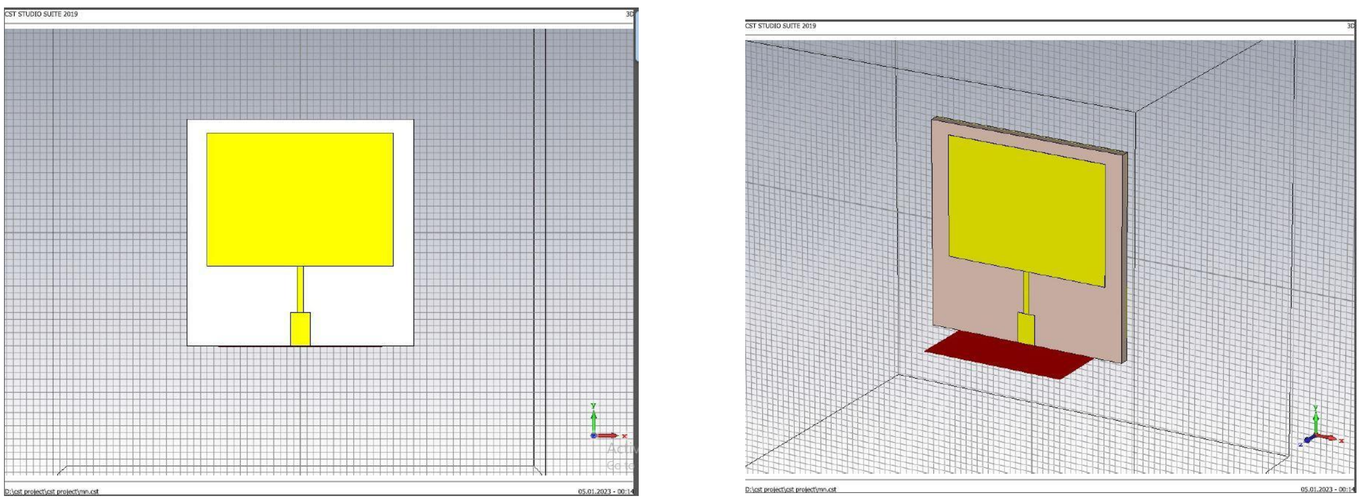


Figure 3.1: Without MTMs

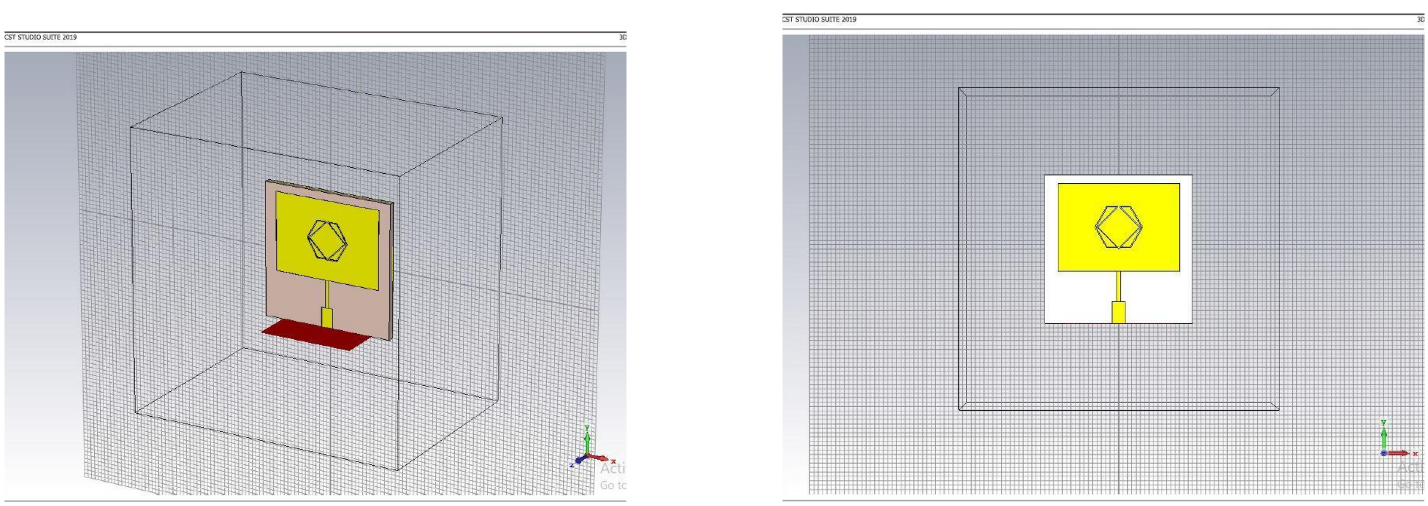
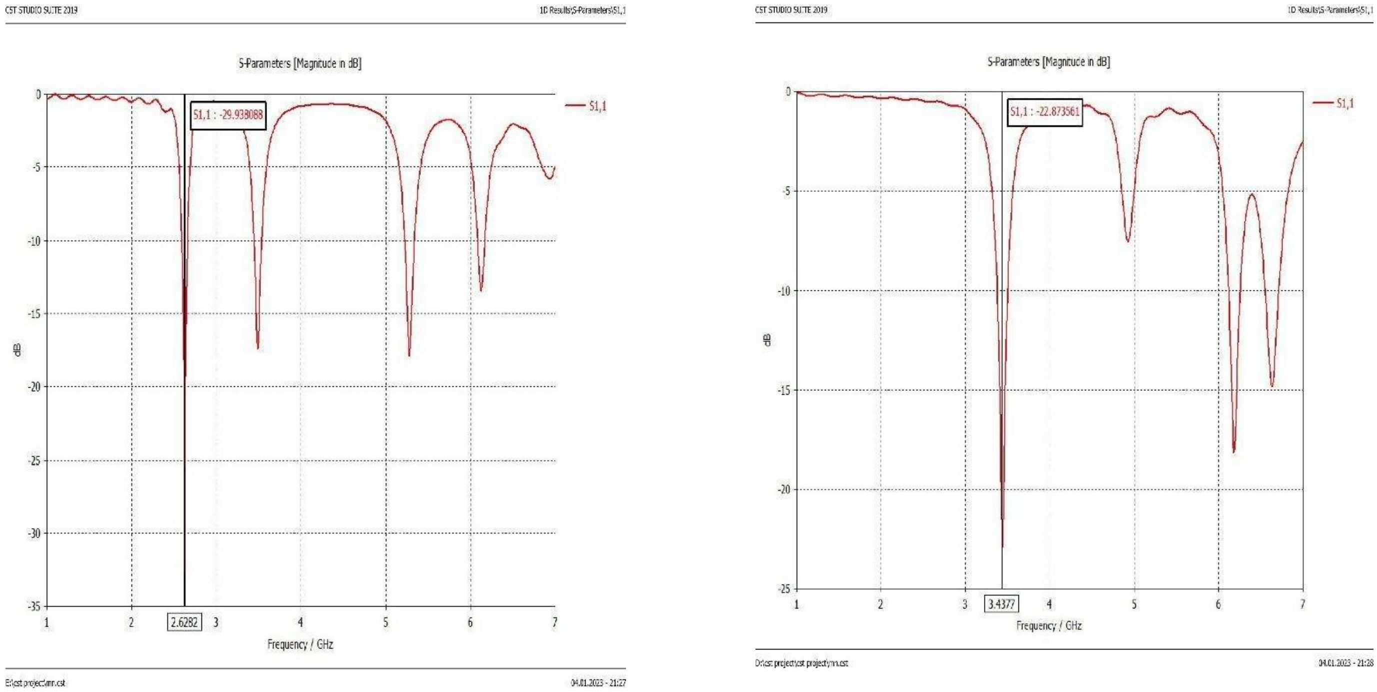


Figure 3.2: With MTMs

4.3Use 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

Using Metamaterial Structures (MTMs) as a Defected Ground Structure (DGS) can help increase the bandwidth of an antenna while reducing its size, depending on the specific needs of the design. This approach is particularly useful for compact and portable devices where space is at a premium. For example, Figure 19 compares two WLAN antennas with a resonance frequency of

2.6282 GHz — one with MTMs and one without. The results show that the antenna with MTMs has both a wider bandwidth and a smaller diameter, demonstrating how MTMs can effectively enhance antenna performance. Table 1 further illustrates the relationship between the increased bandwidth and the reduced size, highlighting the benefits of using metamaterials.

Incorporating metamaterials into antenna design has enabled a significant increase in bandwidth, allowing for better performance in smaller devices without sacrificing efficiency. To achieve the best results, different metamaterial structures and application techniques are chosen based on the antenna's specific requirements. This approach showcases how metamaterials can help design antennas that are not only more compact but also deliver better performance, with enhanced bandwidth and smaller physical dimensions.

References	Parameter Name	Previous Works	Proposed Works
16 17 18	Patch Loading (GHz)	2.45	2.6288
	Ground plane Loading (GHz)	3.2	2.2889
	Reference Impedance (GHz)	2.36	2.6288
	VSWR	2.33	1.1057
	Power Absorbed at all ports (dB W)	14.82	26.47
	Power Accepted Per Ports (dB W)	3	3
	Power Outgoing Per Ports (dB W)	26.86	34.85

Table 2: Previous work VS Proposed work

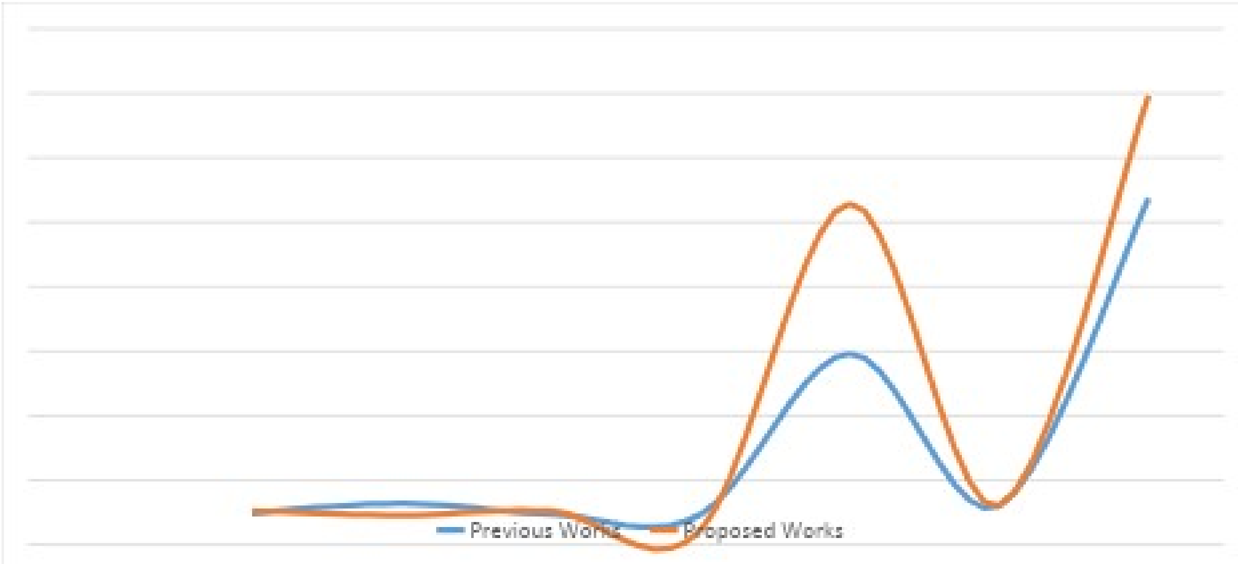


Figure 3.4 Previous work vs proposed work.

The integration of metamaterials into antenna design has significantly broadened its bandwidth. Depending on the specific performance requirements of the antenna, a range of metamaterial structures and design techniques are strategically employed to optimize the antenna's bandwidth. This approach enables the creation of antennas with enhanced capabilities, meeting the diverse needs of modern communication systems.

		Previous	Proposed
I (mm)	Fr (GHz)	Bf (MHz)	Bf (MHz)
0	2.45	328	343
2	3.2	340	356
4	2.36	352	369
6	2.33	356	372
8	14.82	360	375
10	3	364	378

Table 3: Effect of the Variation of the Parameter «I» to the Frequency Characteristics of the Metamaterials Antenna(Naoui et al., 2014)

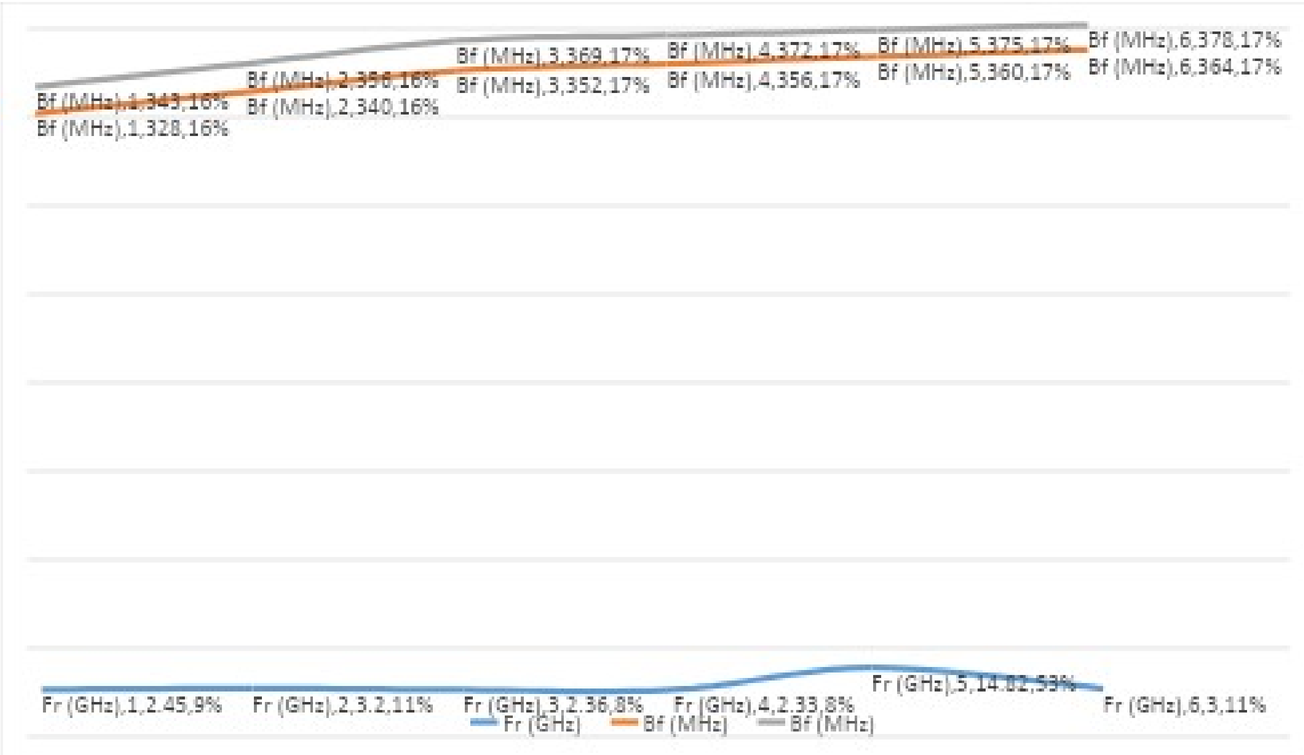


Figure 3.5 Effect of the Variation

(Previous work vs Proposed work)

CHAPTER 5

Thesis Management

5.1 Milestone

The use of metamaterials has advanced significantly, revealing newly developed electromagnetic response functions that are qualitatively are not seen in nature. Utilizing metamaterials in antennas design can not only drastically reduce the antenna's dimensions while simultaneously enhancing other antennas features such as gain, bandwidth, or the production of operating frequencies that are multiband.

Lesson Learned

Increasing Bandwidth Antenna.

Several methods may be employed to increase an antenna's bandwidth, including probe feeding, the employment of different antenna designs, the construction of slots or notches, and The dielectric constant of a substrate with a low thickness. Antenna bandwidth can also be increased by employing multiple-feed systems, combining many antennas into a single system, and adding active components like amplifiers.

Metamaterial Antenna Work

To concentrate radiation from a microstrip transmission line into the components that are sending and receiving, the metamaterial lens in metamaterial antenna systems acts as an extremely effective coupler to external radiation. Therefore, it may be utilized as a keyboard. Systems using metamaterial antennas may be able to expand an antenna's bandwidth.

5.2 CST Software Used

A complete 3D electromagnetic analysis software program for creating, evaluating, and enhancing electromagnetic (EM) systems and components is CST Studio Suite. Metamaterial lenses may be efficiently designed and tested for a range of antenna systems with CST Studio Suite. For applications throughout the electromagnetic spectrum, CST Studio Suite provides electromagnetic field solutions via a single-user interface. A variety of simulations, including Analysis in the frequency-domain, time-domain, transient, and eigenmode may therefore be performed by users.

First, we studied how to design the antenna using the CST program for this article. The basic design is then created, and its operation is shown.

The Antenna Is the Most Difficult To Design.

A tiny antenna with a large band range and good gain is the most difficult criterion for antenna design.

CHAPTER 6

Evaluation of the Thesis's Impact

6.1 Impact on the Economy, Society, and World:

Among their many characteristics are a negative refractive index and electromagnetic cloaking, which are synthetic materials referred to as metamaterials. Metamaterials provide antenna designers with tremendous options to meet the issue of designing a compact antenna with a broad frequency range also good gain. The use of metamaterials in the producing of absorbers, radars system, and antennas will promote growth of markets. Antenna design difficulty also intricacy may be solved using metamaterials.Metamaterials are used by the consumer electronics, automotive, aerospace and defense, and telecommunications equipment sectors, among others.As metamaterials are employed in these industries more often, there will be a greater need for this product. The market is anticipated to grow considerably during the estimated period of time due to the growing demand for metamaterials. The need for metamaterials will increase globally as 5G networks are built and 5G technologies are used more often. The application of metamaterials in the aerospace and military sectors is expected to be the primary force behind the market.

Benefits

It is conscious of even The purpose of a metamaterial will continue to pique interest even after the explanation. Why will it matter so much? In short, it may change whether an item is visible or invisible at particular wave lengths. This suggests that metamaterials will be needed for radar and optical camouflage in the defense and aerospace sectors.

For instance, the wavelength of each type of light—visible, microwave, infrared, ultraviolet, etc.—can be used to distinguish between them. Certain wavelengths may be blocked by metamaterials while others may pass through. It is capable of seeing what is on the other side of an apple if it use metamaterials to Fabric should be made transparent to visible wavelengths. What if it had the ability to destroy everyone or everything? Despite the fact that this idea seems more suited for a science fiction novel, it is actually fairly feasible.

These consequences of wave damping, however, do not limited to light that can be seen; they might also be applied to electromagnetic and acoustic radiation (which ultrasonography cannot detect).

Fields of Application

The fact remains that the item they are concealing disappears, enabling it to see what is behind them, even if it may now detect some distortion through the garments. There are now several prototypes of invisible clothes that the general public may buy. This phenomenon, which is frequently called The terms "cloaking" and "invisibility," have been the focus of a great deal of recent study.The most significant developments in this sector have now been gathered, as it will be evident. They are unquestionably making a cautious but steady entry into the market, though, in the shape of commonplace items or uses, such as in automobile deadlocks, where the driver has a clear vision of what is ahead of him, lowering the risk of crashes and pedestrians running him over. However, Cloaking has impacts that go beyond light's spectrum and range.

It is also feasible to measure the optical, auditory, and electromagnetic components more precisely. It will undoubtedly change the market in the near future with enhanced Among other things, cameras, more potent microprocessors, or medical devices based on ultrasonography with greater resolution. An object must be surrounded by waves of light or sound in order to become invisible.

As said earlier, metamaterials are still a long way from becoming publicly accessible, but their special qualities demonstrate that the only thing standing in the way of application development is individual ingenuity. In a number of domains, including electromagnetic, optical, and acoustics, this method may be useful. It believes that this type of content will be quite popular in the future, therefore it will closely monitor any developments. Because they can change light in ways that were previously unfeasible, metamaterials are essential for invisibility cloaking.

6.2 application of current metamaterials standards

• Metamaterial is frequently used for modifying the elastic properties of materials, improving antenna performance, and absorbing electromagnetic radiation. As a result, this technology has great promise for a wide range of everyday situations. The research in many fields, including computer science and medical, might be enhanced by a multitude of metamaterials.

• A novel class of materials known as metamaterials is revolutionizing many industries, most notably clean technology. Metamaterials have the potential to improve existing objects that may have reached their peak efficiency with little to no human involvement. Metamaterials provide many benefits than just improved performance. We can now overcome industry challenges with the help of entirely new technology.

CHAPTER 7

Conclusions

By utilizing metamaterials, an amazing resource, it can outperform products whose performance was previously thought to have peaked. The antenna may be surrounded by metamaterials, or it may have metamaterials throughout. As technology advances, it can employ the resources at its disposal with increasing skill.The first step to using them as an antenna the unit cells, which are being designed by thought of as atoms, which provide the metamaterial with its unique characteristics at the chosen frequency. Because electromagnetic theory was used in the construction of the metamaterial's unit cells, a broad various antenna topologies, such as lens-type antennas and reflect arrays are possible.

Metamaterials can boost The size, frequency ranges, bandwidth, and power gain of an antenna by 2 dB. An antenna's directivity can also be increased with the usage of metamaterials. Antennas with the right radiation patterns can also be made using metamaterials. Because of its flat shape and simplicity, putting metamaterial onto or near ground plane and patch could a preferable choice in order to increase bandwidth. Antennas with a variety of desirable features can be made by utilizing metamaterials. One approach to obtain high gain at the expense of antenna bulk might be to apply a metamaterial superstrate layer to the patch radiator.

Every effort has been taken to incorporate relevant research into this work, ranging from the evolution of electromagnetic metamaterials throughout history to use of it in improving antenna functionality. We regret that any significant contributions may have been overlooked and for unintentionally leaving out the work of other specialists.

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