Design of an Anisotropic Polarization Conversion Metasurface using Circular Split-Ring Resonators

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by

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May 2024

CERTIFICATE BY THE SUPERVISOR

Certified that **Jatin Sagar** (2K22/MSCPHY/54) has carried out their research work presented in this thesis entitled **"Design of an Anisotropic Polarization Conversion Metasurface using Circular Split-Ring Resonators"** for the award of Master of Science from Department of Physics, Delhi Technological University, Delhi under my supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

Dr. Yogita Kalra
Assistant Professor

Date:

. CANDIDATE'S DECLARATION

I, **Jatin Sagar (2K22/MSCPHY/54)** student of M.Sc. Physics, hereby certify that the work which is being presented in the thesis entitled "**Design of an Anisotropic Polarization Conversion Metasurface using Circular Split-Ring Resonators**" in partial fulfilment of the requirement for the award of the degree of Master in Science, submitted in the Department of Applied Physics, Delhi Technological University is an authentic record of my own work carried out during the period from May 2023 to May 2024 under the supervision of Dr. Yogita Kalra. The matter represented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

Jatin Sagar
(2k22/MSCPHY/54)

This is to certify that the student has incorporated all the corrections suggested by the examiner in the thesis and the statement made by the candidate is correct to the best of our knowledge.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to **Dr. Yogita Kalra**, mentor and supervisor, for her invaluable guidance, support, encouragement, and cooperation throughout the study. Her expertise and constructive feedback were essential in shaping the direction and quality of my work. My gratitude also extends to **Mr. Ankush Dewan**, a PhD scholar for his valuable suggestions and time throughout the research process.

ABSTRACT

This study explores the design of an anisotropic polarization conversion metasurface. An untried design utilizing circular split ring resonator, having Silicon Dioxide (SiO_2) as a substrate which is backed by a thin metallic plate of copper is proposed. The occurrence of polarization conversion by the metasurface in the frequency range of 8 – 9.5 Ghz and 11.8 to 12.5 Ghz is investigated. The findings demonstrate the ability to achieve polarization conversion holding a significant promise for future research since the ability to manipulate polarization of light waves open doors for advancements in display technologies, optical communications, and metamaterial designs with groundbreaking functionalities.

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Chapter 1
Introduction
1.1 Metamaterials

Metamaterials are engineered materials or periodic composites that change electromagnetic properties of materials to get responses that are not observed in nature, [1] or man-made materials with extraordinary properties that can't be found in nature is another definition of metamaterials. The material's structure is responsible for these characteristics, rather than its chemical composition. [2] All the materials which are found in nature like air, water, glass, diamond and such have positive electrical permittivity, magnetic permeability and refractive index, but in metamaterials, these material parameters are negative, which result in the creation of new kinds of scaled-down antennas and microwave devices that can be used in the wireless communications and the defence industries. The electrical permittivity and the magnetic permeability determine a material's response to electromagnetic (EM) waves. In metamaterials, both these parameters are negative.

There is an infinite number of possibilities now that light and other waves may be controlled in their interactions with materials. For example, metamaterials can be engineered to bend light in unusual ways, leading to the development of invisibility cloaking devices; they can also be used to create perfect lenses that focus light without aberrations; in fact, they can be used to create super-lenses that can resolve features much smaller than the wavelength of light, enabling the creation of ultra-quiet materials.

The field of metamaterials is expanding quickly and has the potential to completely transform a wide range of businesses. Although they are still in the early phases of development, scientists are always thinking of creative and novel applications for them.

1.1.1 Brief History of Metamaterials

The Greek word metamaterial, which means superior or beyond, is the source of the name. It is a synthetic artificial substance made by fusing metals and plastic together with other materials. [3]

The earliest metamaterials were created in the early 20th century as a result of the concept of a substance with a negative refractive index. The earliest metamaterials were developed primarily by microwave interaction, which involved a grid of tiny metallic resonators. Since then, metamaterials have been created that allow for the manipulation of light, sound, and other electromagnetic radiation types. In 2006 (Schurig et al., 2006), researchers at Duke University created the first "invisibility cloak" by using metamaterials to deflect light around a small object, rendering it invisible to the unaided eye. Early in the 2010s, metasurface's experimental demos first surfaced. Advances in nanofabrication techniques made it possible for researchers to construct structures with precise dimensions and forms at the nanoscale, opening the door for the creation of metasurfaces. Since then, metasurfaces have helped to make a variety of optical devices conceivable, including holograms, polarizers, and lenses. Additionally, they have been applied in fields like as acoustic and thermal engineering. More accurate light manipulation techniques have opened fascinating new possibilities in fields including imaging, sensing, and communications. [4].

1.1.2 Passive Metamaterials

Metamaterials labelled as passive don't need an outside energy source to function. They achieve this by relying on the material's natural structural characteristics, which alter the behaviour of the radiation. They are made up of fixed components that are organized in a particular way to produce the intended electromagnetic wave response. The structure of the material determines its qualities, such as permeability (interaction with magnetic fields) and permittivity (interaction with electric fields), which are not affected by external factors.[4]

Scientists are able to produce a variety of electromagnetic reactions that are not present in natural materials by carefully crafting these structures. Materials that are passive can control the propagation of light by bending it in novel ways, which could result in cloaking technologies.
It has improved absorption, for use in solar cells or noise cancellation, capture particular light or sound wavelengths.

To create new kinds of lenses or ideal absorbers, it is possible to achieve a negative refractive index, a feature not seen in natural materials.
Passive metamaterials have advantages in terms of ease of use and low maintenance. Their capacity to alter their attributes dynamically, though, might be constrained. Scientists are continuously creating new designs and investigating the possible uses of passive metamaterials in a variety of domains.

1.1.3 Active Metamaterials

Metamaterials that are active require an external energy source to change the characteristics of light. They also contain other components, such as semiconductors or small circuits, which enable external control of their properties. This external control may come from stimuli such as light or electricity. Active metamaterials have the ability to dynamically alter their characteristics in reaction to outside inputs, in contrast to their passive counterparts. This provides access to a greater variety of features and applications. Active metamaterials include extra parts such as miniature motors, sensors, or pliable materials in their construction. External sources such as light, magnetic forces, or electricity can have an impact on these elements. Scientists can modify the material's real-time reaction to light, sound, or other waves by adjusting these integrated components.

Some main advantages of active metamaterials are dynamic control, in which adaptable functionalities are made possible by the flexibility to adjust attributes as needed. They are also reconfigurable, by allowing active metamaterials to be designed to alternate between several states, more flexibility is possible. They also can overcome restrictions in a way that they can take care of passive metamaterial restrictions like fixed responses or constrained bandwidths.

Some interesting possible uses for active metamaterials are Smart cloaking devices, in which substances with the ability to change their characteristics in order to conceal objects from particular light wavelengths, reconfigurable lenses which are active lenses that can change their focus or manipulation of light in response to outside input, antennas that can dynamically alter their characteristics to maximize signal transmission or reception are known as metamaterial antennas, materials with the ability to actively alter to block out particular noise frequencies are known as noise-cancelling materials. [4]

The field of active metamaterials is one that is fast developing and has the potential to completely transform a number of industries. Research is going on to realize the full potential of these futuristic materials and bring them to reality, even if challenges still exist in areas like miniaturization and energy usage.

1.1.4 Metasurfaces

Metasurfaces are basically two-dimensional (2D) versions of metamaterials. Metasurfaces possess distinctive properties that enable them to block, absorb, concentrate, scatter, or steer waves from microwave to visible frequencies, both on the surface at a grazing incidence angle and in space at normal and oblique incidence.[5]

Metasurfaces are organized on a scale smaller than the wavelength of light, giving them the ability to bend and refract light in novel ways. Though conceptually similar to 3D metamaterials, metasurfaces are often thinner and easier to construct. By manipulating the phase, amplitude, and polarization of light, metasurfaces open new possibilities in optics and photonics. [6]

Notable differences between a metasurface and a metamaterial are 1. dimensionality, where metasurfaces are simply thin films patterned with subwavelength constituents, whereas metamaterials are three-dimensional structures. 2. Fabrication is easy, since metasurfaces are more straightforward 2D materials, they are typically less expensive and easier to make and 3. good light manipulators meaning, metasurfaces are excellent in bending, focusing, and producing holograms by adjusting the light's wavefront.

A thin layer patterned with microscopic, recurring structures known as meta-atoms makes up a metasurface. These meta-atoms can have many configurations, sizes, and forms. Light's interaction with the metasurface can be manipulated by scientists through meticulous design of the meta-atoms. They enable a variety of functions by adjusting the polarization, amplitude, and phase of light.

Metasurfaces offer a number of benefits like, compactness, since they are perfect for smaller devices due to their thin profile. Versatility, since they are capable of carrying out a range of light manipulation operations that would often call for large lenses or gratings and Flat optics, since they provide a flat substitute for traditional curved lenses, opening up new design options.

There are many uses for metasurfaces, like, making incredibly thin lenses for virtual reality, phones, and cameras is known as "flat lensing." Managing the intensity and direction of light beams for uses such as laser cutting, and optical communication called Beam shaping. Producing holographic images with high resolution for use in 3D printing, security features, or displays. Filtering or wavefront shaping, among other uses, by diffracting light in particular ways called Meta-gratings. [7]

The topic of metasurfaces is expanding quickly and holds great promise for upcoming innovations. Their inventive light manipulation techniques could lead to breakthroughs in communication, optics, and other areas.

1.1.4.1 Isotropic Metasurface

These behave the same way regardless of the light's polarization (orientation of the electric field). Their properties are uniform in all directions across the surface.[8] An isotropic metasurface is distinguished from other metasurfaces by its special ability to respond uniformly to polarization of light.

An isotropic metasurface is distinguished by its polarization independence. It handles light polarizations all the same way. This implies that regardless of the orientation of the electric field in the light wave, the metasurface's ability to reflect, transmit, or bend light stays constant which is its defining characteristic.

Isotropic metasurfaces have various benefits like a simplified design, where the design process can be made simpler by doing away with the requirement to take various polarizations into account. They work well with a wider variety of light sources, some of which may lack a distinct polarization, are less complex and more efficient and compact devices may result from the incorporation of polarization-independent behaviour.

Researchers have accomplished the isotropic characteristic by structural designs, where it is essential to carefully place and align the meta-atoms, or building blocks, on the metasurface. Polarization-dependent effects can be neutralized by geometries and symmetries and material selection where isomerization can occasionally be enhanced by mixing materials that respond similarly to one another across polarizations.

There are several applications where polarization independence is desired that isotropic metasurfaces may be useful for like developing flat lenses known as "meta-lenses" that function well in any light polarization is helpful for small cameras and displays. It can also be used in wavefront shaping, in which, regardless of the polarization of the incoming light, manipulating light wavefronts for purposes such as holography or beam shaping. Isotropic metasurfaces can also be essential for the efficient operation of terahertz devices, as terahertz waves frequently lack well-defined polarization.

Research on the creation of isotropic metasurfaces is still ongoing. These distinctive metasurfaces could be crucial to the development of photonic technology in the future as researchers continue to investigate new materials and improve design methods.

1.1.4.2 Anisotropic Metasurface

Anisotropic metasurfaces exhibit a directional dependence in their response to light. Their properties vary based on the polarization of the incoming light. Think of them as having a specific "grain" that affects how light interacts with them depending on the direction of the electric field. [9]

These metasurfaces enable functionalities which are not achievable with isotropic ones. For example, they can create devices that separate different polarizations or convert between them.

These metasurfaces can separate light beams based on their polarization, useful for various applications like optical communication or sensor design.

Anisotropic metasurfaces can act as waveplates, introducing a specific phase shift depending on the light's polarization. This enables functionalities like polarization conversion or circular polarization control.

Anisotropic metasurface design requires careful consideration of the factors such as, shape and arrangement of the meta-atoms in which the metasurface's interaction with various polarizations is dictated by the precise sizes, shapes, and orientations of the meta-atom building pieces. Materials with varying responses to different polarizations can be used to enhance the anisotropic effects.

The topic of anisotropic metasurfaces is an area that is rapidly advancing and has enormous potential for photonic future technologies. These adaptable metasurfaces can be crucial as researchers develop novel materials and design methodologies for advanced optical devices like developing small, effective devices for beam shaping, polarization control, and innovative displays.
In Integrated photonics where, facilitating the creation of compact photonic circuits with sophisticated features through manipulation of light polarization. And creating sensors that take use of the relationship between light polarization and the characteristics of the substance being sensed called metamaterial sensing.

1.1.5 Split-ring Resonators

Split-ring resonators (SRRs) are a fundamental building block in the field of metamaterials. They are artificially engineered structures designed to interact with electromagnetic waves in unique ways. An SRR consists of a pair of concentric metallic rings, typically etched on a dielectric substrate.

A small gap is introduced on opposite sides of the rings, disrupting the current flow and creating a resonant cavity. This gap is crucial for the SRR's functionality. [10] Concentric metallic rings which are usually circular or square with a gap on opposite sides is fabricated on a dielectric substrate.

For electromagnetic waves, especially those in the microwave and terahertz range, SRRs function as small resonators. Resonance occurs at certain frequencies when the current flow is disrupted by the space between the rings. Scientists can modify the SRRs' size, shape, and gap to customize the resonant frequency for a certain purpose.

In order to create metamaterials with negative permeability, SRRs are essential. This is a unique characteristic in which the material responds to light magnetically in the opposite direction than natural materials do.
SRRs can be combined with other metamaterial components to provide researchers unusual electromagnetic features such as negative refraction. This may result in odd light bending or the creation of ideal lenses, among other occurrences.

SRRs have various applications like Metamaterial antennas, bandpass filters, sensors, perfect absorbers. Due to their capacity to regulate electromagnetic waves at particular frequencies, these smaller antennas have improved performance. These devices are important for radio frequency communication because they filter particular electromagnetic wave frequency ranges. By detecting a material's impact on resonance behaviour, SRR-based sensors can identify a material's existence or characteristics. The ability to entirely absorb certain light wavelengths with the use of metamaterials with SRRs opens up new uses, such as solar energy harvesting and (yet undeveloped) cloaking devices.

Some of the advantages of SRRs are, they are relatively simple to fabricate using standard lithography techniques. They provide a great deal of design freedom in terms of adjusting their resonance characteristics, and they can be used in conjunction with different metamaterial components to accomplish a range of functions.

All things considered; split ring resonators are an essential component of the metamaterials' universe. Their capacity to control electromagnetic waves at the nanoscale creates fascinating opportunities across a range of scientific and technological domains.

1.2 Polarization

Polarization is a property of certain electromagnetic radiations in which the direction and magnitude of the vibrating electric field are related in a specified way Light waves are transverse: that is, the vibrating electric vector associated with each wave is perpendicular to the direction of propagation. A beam of unpolarized light consists of waves moving in the same direction with their electric vectors pointed in random orientations about the axis of propagation. Plane polarized light consists of waves in which the direction of vibration is the same for all waves. In circular polarization the electric vector rotates about the direction of propagation as the wave progresses. Light may be polarized by reflection or by passing it through filters, such as certain crystals, that transmit vibration in one plane but not in others [11].

Despite its uniform appearance, light has a hidden quality known as polarization. Consider throwing a rope in a wave-like manner. The rope's up-and-down movement is comparable to a light wave's electric field. This electromagnetic field vibrates randomly in unpolarized light. On the other hand, the electric field vibrates in a particular plane in polarized light.

Three primary categories of polarization exist:
With linear polarization, the electric field vibrates in a single plane, resembling a rope that shakes vertically or horizontally. Consider polarized sunglasses, which reduce glare by blocking light vibrations in a single plane.
Circular polarization: Either clockwise (to the right) or counterclockwise (to the left) rotation of the electric field is seen. Certain displays in 3D glasses make use of this feature.
Elliptical polarization: In this case, the electric field traces an elliptical path and is in between linear and circular polarization.

Polarization is important for a number of applications like in Liquid crystal displays (LCDs) in which by selectively permitting light with a certain polarization to pass through, LCDs' liquid crystals function as microscopic shutters to produce images.
In Optical fibers where, when it comes to communication, optical fibers must maintain their polarization. When distinct polarizations move through a fiber at marginally different rates, light leaks may happen. In Photography, by polarizing light, certain filters can reduce glare and enhance colours in shots, particularly those of landscapes with reflections.

Researchers are also looking into the possibility of polarization in metamaterials, which are synthetic materials with special qualities. Through meticulous structural design, they are able to regulate the way light interacts with various polarizations, resulting in functions such as waveplates or polarization beam splitters that govern light in certain ways. Gaining an understanding of polarization helps one appreciate light and how it may be used to create novel technology.

1.2.1 Cross Polarization Conversion

Through the process of cross-polarization conversion, light waves can be controlled by shifting the direction of their electric field. By this process, light that is in one polarization state, such as vertically polarized light, becomes in another, such as horizontally polarized light. This conversion is typically achieved using specially designed structures called metasurfaces. [12]

Applications for cross-polarization conversion are diverse and span several industries such as in Optical Communication where preserving a certain polarization might be important in fiber optic communication. The polarization variations that happen during signal transmission can be adjusted by using polarization converters.
In display technologies, to produce different images for each eye, certain 3D display systems manipulate light's polarization. These polarized light streams are guided in part by cross-polarization converters.
In Imaging Methodologies, where the polarization of light can be controlled for the advantage of several imaging and microscopy procedures. Through conversion, scientists can examine samples and determine particular details from their polarization response. In metamaterials, it is possible to create engineered materials with effective cross-polarization conversion. This provides opportunities for the development of new optical devices or ideal absorbers, for example.

Depending on the intended usage and wavelength range, cross-polarization conversion can be accomplished using a number of methods like, Waveplates where a phase shift between two polarizations is introduced by these birefringent materials. It is possible to change the polarization of light by carefully selecting the type and direction of the waveplate.
In Prisms and Gratings, by manipulating the various polarization components of light, specially made prisms or gratings may convert light.
In Metamaterial Converters, where a wide variety of wavelengths can be efficiently converted to cross-polarization using engineered metamaterial structures.
The future of cross polarization conversion looks promising, and scientists are currently researching cross-polarization conversion and creating new materials and methods for effective and adaptable conversion across many light

spectrums. We may anticipate seeing more and more uses for this technology as it develops, from better communication systems to cutting-edge imaging methods and unique optical gadgets.

1.2.1.1 Applications of Cross Polarization Conversion

Cross-polarization conversion has potential applications in fields such as, Liquid Crystal Displays (LCDs), improving contrast and viewing angles in LCDs by controlling the polarization of light. Optical Communications, enabling more efficient data transmission in fibre optic systems by utilizing multiple polarization states. 3D Displays, creating high-quality 3D visuals by precisely controlling the polarization of light reaching each eye. Medical Imaging, enhancing the sensitivity and specificity of certain medical imaging techniques by utilizing polarized light. [13]

Chapter 2 Literature Review

M. Ismail Khan has designed and simulated a novel microwave metasurface capable of manipulating light polarization across three distinct frequency bands. This tri-band cross-polarization converter (CPC) utilizes split-ring resonators (SRRs) with a unique double-split configuration, etched on a thin FR4 dielectric substrate backed by a metallic ground plane. The design achieves efficient CPC for both normal and oblique light incidence, with the multi-band conversion attributed to precisely engineered plasmonic resonances at the desired frequencies. Notably, the sub-wavelength unit cell size, thin substrate, and optimized SRR structure all contribute to an angle-independent response, making this metasurface a promising candidate for various practical applications in the microwave regime.[14]

M. Ismail Khan also designed, built, and tested a broadband metasurface that can convert the polarization of microwave light across a wide range of frequencies. This metasurface, made from coupled split-ring resonators on a thin substrate, efficiently flips the polarization of light waves striking it head-on or at angles. The secret to its broad range and angle-insensitivity lies in its design – multiple resonances and a sub-wavelength structure with symmetrical features. This innovative design paves the way for practical applications of such polarization-manipulating metasurfaces in the microwave regime, with simulations and experiments confirming its effectiveness.
Because of their many applications in planar optics, anomalous refraction, angular momentum of light, optical vortex formation, polarization conversion (PC), etc., metamaterial based planar metasurfaces have been the subject of intense research in recent years.
The electromagnetic response of such surfaces such as reflection and transmission coefficients can be controlled by a properly designed sub-wavelength unit cell rendering the surface an effective permittivity and permeability. As many phenomena are polarization sensitive, therefore, a significant part of the metasurface research is focused on such surfaces that can control and manipulate the polarization of the electromagnetic (EM) waves. Although polarization of the electromagnetic waves can be manipulated through conventional methods such as optical activity of the crystals and Faraday Effect, however, such methods require bulky volume and are effective only for very narrow bandwidth. [15]

One of the fundamental characteristics of electromagnetic waves that is useful for delicate measurements and signal transmission is polarization. Traditional techniques for enhanced polarization control achieve only restricted performance and place strict demands on material qualities. We demonstrated terahertz polarization converters based on metamaterials that are ultrathin, broadband, and incredibly efficient. These converters can flip a linear polarization state into its orthogonal one. These findings led us to design metamaterial structures that enable near-perfect anomalous refraction. Our work enables emergent metamaterial functions for applications in the challenging terahertz-frequency region and provides new avenues for the development of high-performance photonic devices. [16]

In a breakthrough for plasmonic metasurfaces, researchers have introduced a design that overcomes limitations of previous approaches. Traditionally, these surfaces rely on metallic resonators that suffer from low efficiency and energy loss. The new design tackles this challenge by replacing metal with high-refractive-index silicon cut-wires backed by a silver ground plane. This innovative approach has been experimentally shown to achieve remarkable results: over 98% efficiency in converting light wave polarization across a broad infrared wavelength range, with significantly reduced energy loss compared to metal-based designs. The research team further demonstrates the metasurface's functionalities by converting linear polarization and generating optical vortex beams with high efficiency over a wide range of wavelengths. This development, using silicon cut-wires instead of traditional metallic components, paves the way for creating ultra-efficient metasurfaces that can operate at even higher frequencies, opening doors for next-generation photonic devices. [17]

Chapter 3 Design and Modelling

The simulations were run on Computer Simulation Technology (CST) software.

A metasurface is designed having a circular SRR of gold on top, backed by a plane metallic sheet of copper, and Silicon Dioxide as substrate.

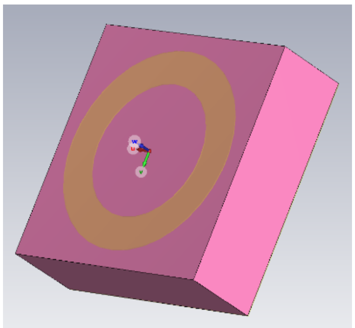

Figure 3.1(a): A schematic diagram of the original Metasurface.

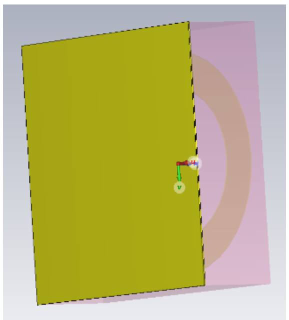

Figure 3.1(b): The Metasurface is backed by a copper plate.

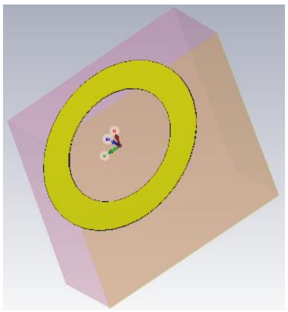

Figure 3.1(c): A circular split ring resonator is placed on top of the Metasurface

The physical dimensions of the metasurface are in millimetres: length = 7, breadth = 6, width of the SRR = 1, height of the metasurface = 2.4 and thickness of the metallic copper plate and SRR = 0.035

The substrate used here is Silicon Dioxide (SiO_2) having δ=0.001, Thermal conductivity = 1.1 W/K/m and Specific heat = 680 J/K/kg with a metallic sheet of copper having electric conductivity of $5.8x10^7$ S/m, Thermal conductivity = 401 W/K/m, and Specific heat = 390 J/K/kg, placed on the back of the metasurface

A SRR of gold is used to model the metasurface having Electric conductivity = $4.561x10^7$ S/m, Thermal conductivity = 314 W/K/m, and Specific heat = 130 J/K/kg

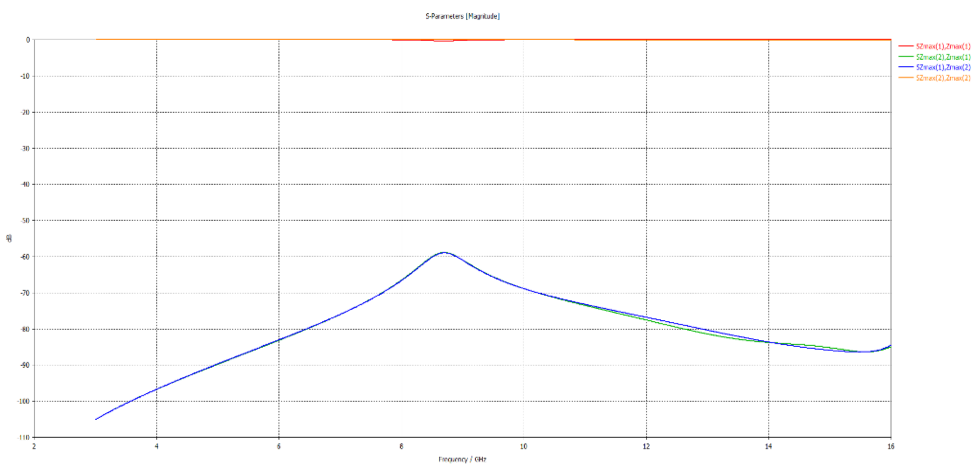

Figure 3.2: S – parameters of the original metasurface. Plotted Frequency vs dB

The Scattering parameter is shown in the graph for the original metasurface with SRR having no cuts. The graph is plotted between Frequency and dB. The peak is generated in the frequency band of 8 - 9.5 Ghz.

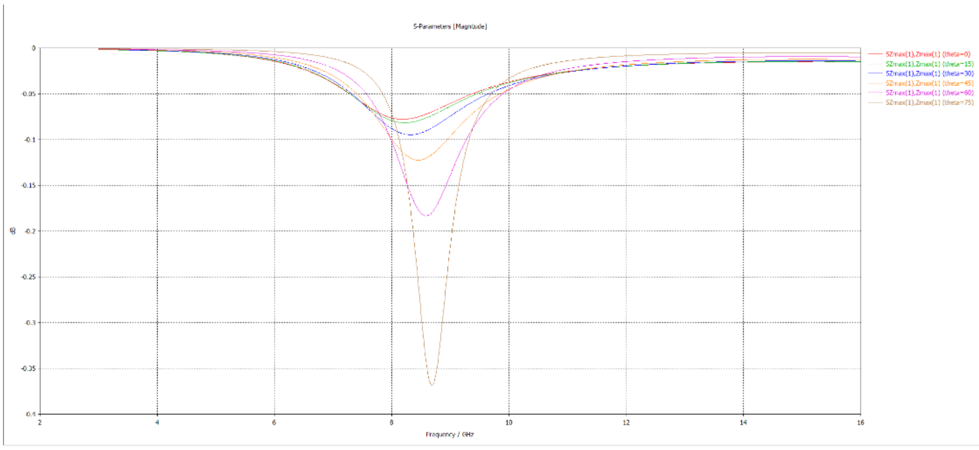

Figure 3.3: Co-polarized reflection coefficient when the incident field is x polarized.

The graph shows scattering parameters for varying theta from 0 to 75.

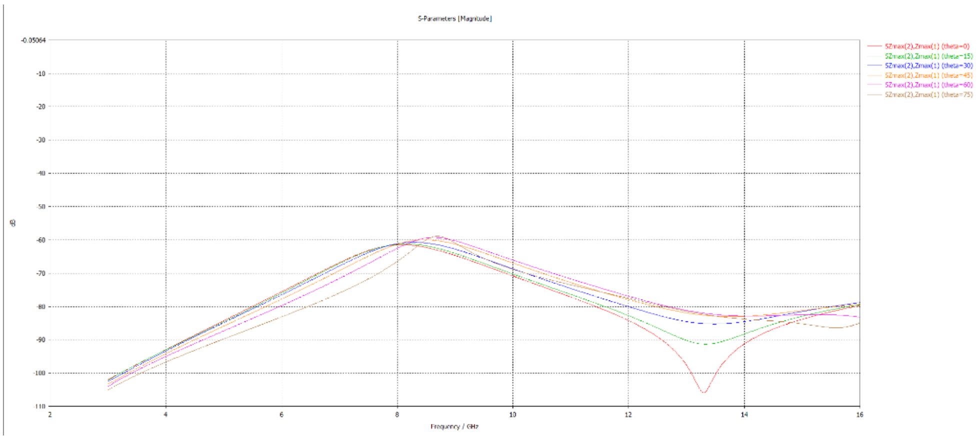

Figure 3.4: Cross-polarized reflection coefficient when the incident field is x polarized.

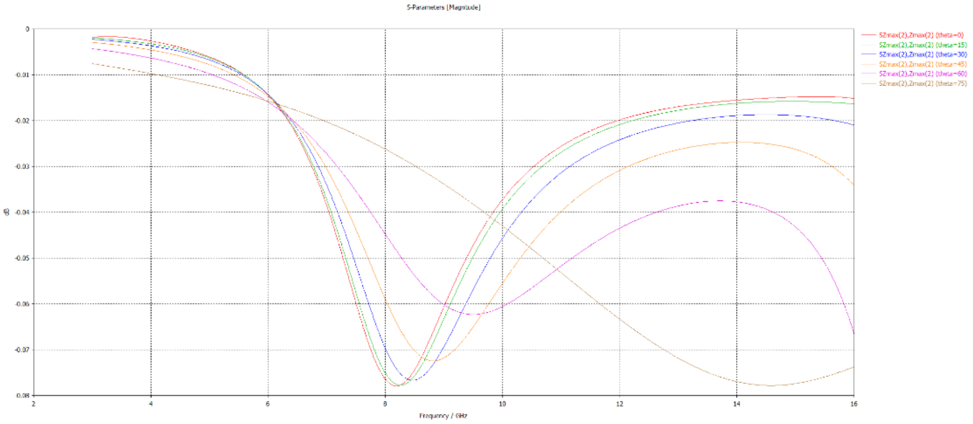

Figure 3.5: Co-polarized reflection coefficient when the incident field is y polarized.

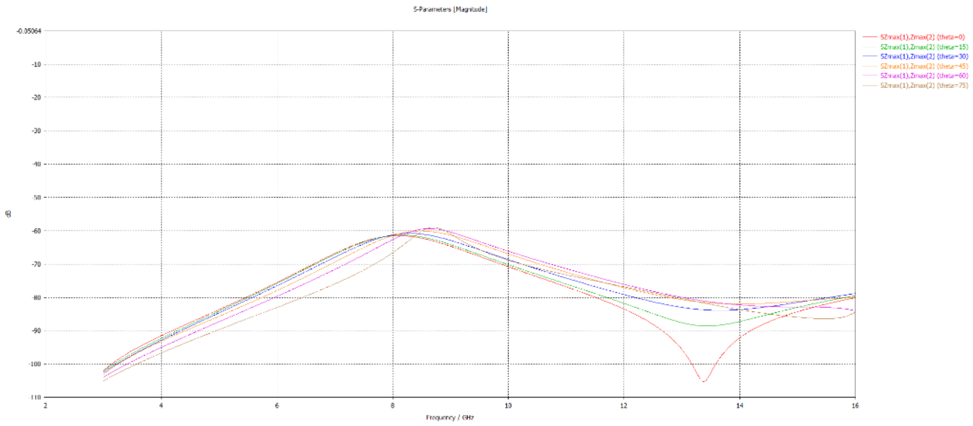

Figure 3.6: Cross-polarized reflection coefficient when the incident field is y polarized.

Cross polarization conversion is observed in a single band of 8 – 9.5 Ghz when having a SRR on the metasurface with no cuts.

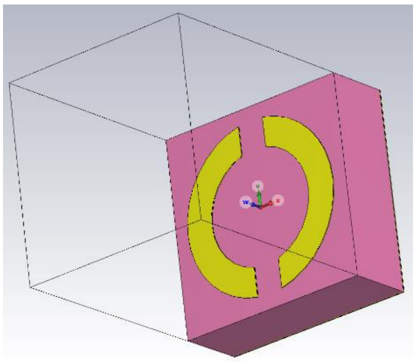

Figure 3.7(a): An updated model of the proposed Metasurface

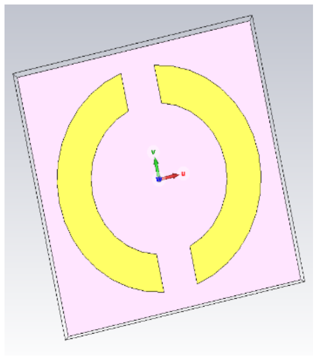

Figure 3.7(b): A circular SRR with two cuts is placed on top of the Metasurface.

An updated model of the proposed metasurface is designed having two cuts in the SRR in the opposite direction.

The physical dimensions of the updated metasurface are in millimetres: length = 7, breadth = 6, width of the SRR = 1, length of the cut of the SRR = 1, height of the metasurface = 2.4 and thickness of the metallic copper plate and SRR = 0.035

The substrate used here too is Silicon Dioxide (SiO_2) having δ=0.001, Thermal conductivity = 1.1 W/K/m and Specific heat = 680 J/K/kg with a metallic sheet of copper having electric conductivity of 5.8x107 S/m, Thermal conductivity = 401 W/K/m, and Specific heat = 390 J/K/kg, placed on the back of the metasurface

A SRR of gold is used to model the metasurface having Electric conductivity = 4.561x107 S/m, Thermal conductivity = 314 W/K/m, and Specific heat = 130 J/K/kg

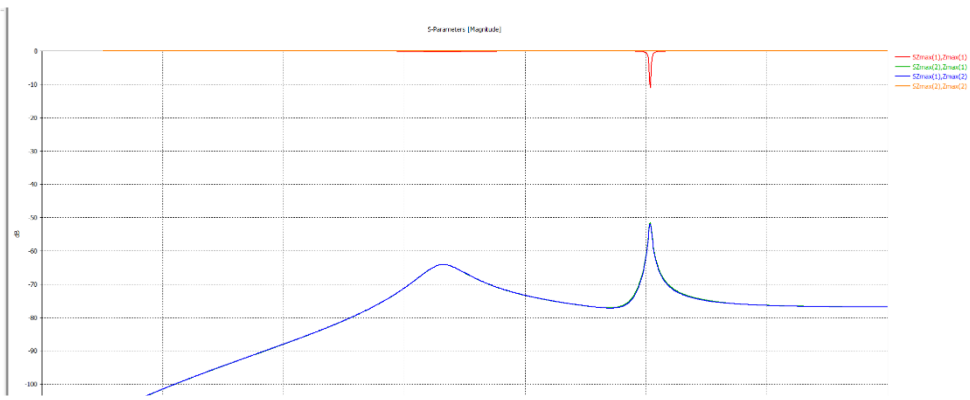

Figure 3.8: S – parameters of the updated metasurface, plotted a graph of frequency vs dB

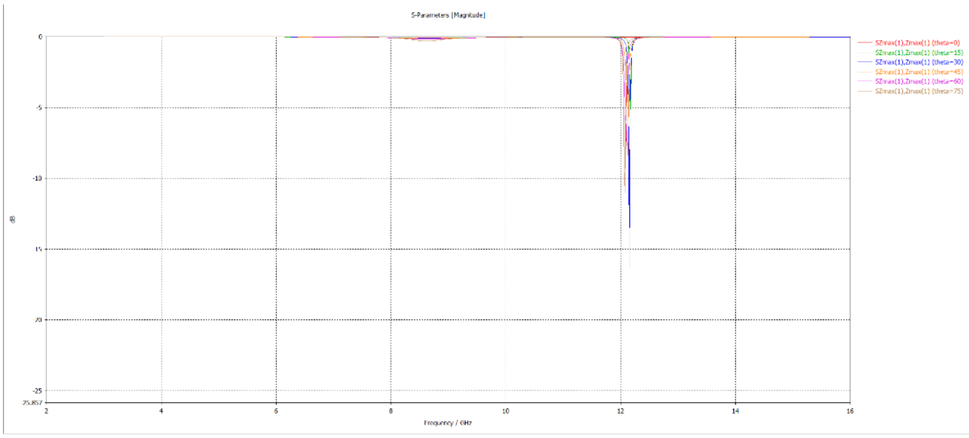

Figure 3.9: Co-polarized reflection coefficient.

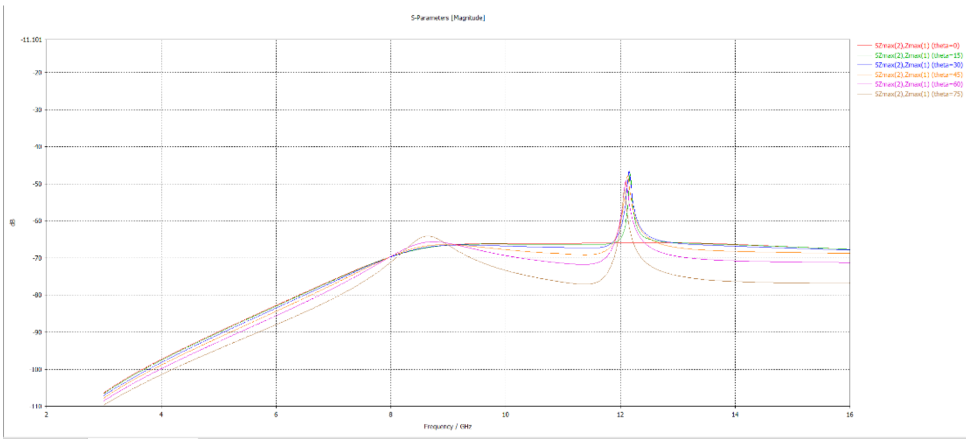

Figure 3.10 Cross polarized reflection coefficient

4. Results and Findings

Cross Polarization conversion is observed in two distinct frequency bands of 8 - 9.5 Ghz and 11.8 – 12.5 Ghz, when having a SRR with two cuts on the metasurface.

Cross polarization conversion is observed in a single band of 8 – 9.5 Ghz when having a SRR on the metasurface with no cuts.

The simulation is operated in the frequency range of 3 to 16 Ghz, using parametric sweep of 15 steps from theta = 0 to theta = 75.

Chapter 5 Future Scope

Cross-polarization conversion metamaterials hold significant promise for future research due to their unique ability to manipulate the polarization of light waves. Cross-polarization converters offer greater control over light compared to traditional methods.

By optimizing the polarization of light in displays, researchers can achieve improved contrast, viewing angles, and energy efficiency in LCDs and other display technologies.

Precise control over light polarization can enable more efficient data transmission in fiber optic communication systems. Different data streams can be encoded on various polarization states, increasing the overall data capacity.

Current research focuses on cross-polarization converters with anisotropic properties, meaning their response depends on the incoming light's direction. This opens doors for designing metamaterials with even more intricate light manipulation capabilities. Future research might explore:

Metamaterials that can dynamically change their polarization conversion properties based on external stimuli (light, electric field, etc.) could be developed.

Combining cross-polarization conversion with other metamaterial properties like cloaking or negative refraction could lead to entirely new classes of metamaterials with transformative applications.

Cross-polarization converters can be integrated into various devices to achieve novel functionalities such as, metamaterial sensors that utilize changes in polarization for detection purposes could be developed for medical diagnostics, environmental monitoring, or security applications or lenses made from cross-polarization conversion metamaterials could offer unique properties like focusing light with specific polarizations or creating polarization-selective filters.

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