PROJECT REPORT ON

LINEAR - CROSS AND LINEAR - CIRCULAR REFLECTIVE TYPE POLARIZER FOR SUB-THZ REGIME

submitted in partial fulfillment of the requirement for the award of B.Tech Degree in Electronics and Communication Engineering of APJ Abdul Kalam Technological University by

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JUNE 2022

DECLARATION

We undersigned hereby declare that the project report ("**LINEAR - CROSS AND LINEAR - CIRCULAR REFLECTIVE TYPE POLARIZER FOR SUB-THZ REGIME**") , submitted for partial fulfillment of the requirements for the award of the degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under supervision of **Dr. Nissan Kunju**, Assistant Professor, Department of Electronics and Communication Engineering. This submission represents our ideas in our own words and where ideas or words of others have been included, We have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in our submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma, or similar title of any other University.

Place: Kollam

Date: 06/06/2022

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CERTIFICATE

This is to certify that the project report entitled **"LINEAR - CROSS AND LINEAR - CIRCULAR REFLECTIVE TYPE POLARISER FOR SUB-THZ REGIME"** is a bonafide account of the report of the project presented by **Fema Mathew (TKM18EC059), Fibin Babu (TKM18EC061), Karthika Suresh (TKM18EC069), Krishnadas M D (TKM18EC072)** in partial fulfilment of the requirement for the award of Bachelor of Technology in Electronics and Communication Engineering of APJ Abdul Kalam Technological University during the academic year 2021-2022.

Dr. NISSAN KUNJU	**Prof. AJITHA S S**	**Prof.ABID HUSSAIN**
Project Guide	Project Coordinator	Head of Department

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It is with great pleasure and pride that we present this report before you. At this moment of triumph, it would be unfair to neglect all those who helped us in the successful completion of this report.

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ABSTRACT

The polarization converter mainly converts the linearly polarized beam into the cross-polarized beam and circularly polarized beam. In this paper, the design of a reflective type linear-linear and linear-circular polarization converter at the sub-THz frequency regime is detailed. The designed unit cell of reflective polarizer consists of four squares at each corner with a long bar placed diagonally joining two squares printed on the top of polyamide substrate terminated with the gold ground on the other side. Post simulation results show a linearly polarized (x/y) incident wave converted to its cross (y/x) component in three frequency bands (0.46- 0.50THz, 1.08- 1.57THz, and 2.00 -2.02 THz) after reflection. The reflected wave would also be circularly polarized in five different frequency bands (0.43-0.45 THz, 0.53-0.94THz,1.61-1.64 THz, 1.96-1.99 THz, and 2.04-2.06 THz). The proposed structure has a unit-cell periodicity of 0.28 λ_L and an effective thickness of 0.0026 $\lambda_{L,}$ where λ_l is the operating frequency. For linear-cross conversion, the proposed design exhibits a stable response up to 40°, while for linear-circular conversion, it shows a stable response up to 30°. The authors believe that the proposed geometry offers various benefits, including simplicity, compactness, and angular stability. It is employed in real-time applications such as polarization beam splitters and time-domain spectroscopy, where conversions are the most important factor.

Keywords—Frequency Selective Surface (FSS), Linear-Cross, Linear-Circular, Polarization Conversion Ratio (PCR).

CONTENTS

ABBREVIATION

PCR	Polarization Conversion Ratio
TE	Transverse Electric
TM	Transverse Magnetic
EM	Electromagnetic
FSS	Frequency Selective Surface
LTC	Linear to Cross
FEM	Finite Element Method
AR	Axial Ratio
FBW	Fractional Bandwidth
LHCP	Left Hand Circularly Polarized
RHCP	Right Hand Circularly Polarized

NOTATION

THz	Terahertz
GHz	Gigahertz
µm	micrometer
λ_L	Operating frequency
dB	decibel
$\overrightarrow{E_l}$	Incident field component
$\overrightarrow{E_r}$	Reflected field component
r_{yy}	Co- polarization reflectance
r_{xy}	Cross polarization reflectance
η	Polarization Conversion Ratio

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Nowadays, terahertz (THz) science and technology are advancing at a tremendous pace. However, the absence of adequate equipments for controlling THz waves has stifled the advancement of THz technology. As a result, THz device advancements that can manipulate the challenging THz waves in novel and flexible ways have gained a considerable attention. Polarization converters, as a programmable THz device, can efficiently modify the polarization of electromagnetic (EM) waves and have been drawing increasing attention in a variety of applications, including antenna design and target stealth. The large shape of traditional wave polarization control devices, on the other hand, is not conducive to integration.

Polarization is the property of the transverse EM waves that define the spacial alignment of the electric field oscillations. Electromagnetic waves, such as visible light and microwaves, have orthogonal electric and magnetic fields that run in opposite directions from the wave's propagation path. The polarization of an electromagnetic wave describes the amplitude and direction of the wave's electric field. A radiated electromagnetic wave's polarization is described as "that attribute of a radiated electromagnetic wave characterising the time-varying direction and relative magnitude of the electric field vector; the trace and magnitude of the electric field vector are observed in the direction of light propagation." The polarization conversion phenomenon is commonly observed in natural crystals such as quartz and tourmaline. However, because to the weak anisotropy of these crystals, these designs have a number of drawbacks, including higher thickness, which results in bulkier, heavier power dissipation, and is economically unviable. Artificial anisotropy, on the other hand, can be engineered in the same way as these crystals using metamaterials.

Metamaterials are made up of periodic subwavelength metal/dielectric structures that resonantly couple to the electric and/or magnetic components of incident electromagnetic fields, giving them unique features not found in nature. Metamaterials that are properly built can alter electromagnetic radiation or sound waves in ways that bulk materials cannot. A lot of research has gone into those that have a negative index of refraction for wavelengths. These are referred to as negative index metamaterials. Superlenses can be made with metamaterials. Such a lens might be able to image below the diffraction limit, which is the lowest resolution that ordinary glass lenses can attain. It got attention in the optics research community in recent years due to its exceptional EM wave manipulation capabilities, which have led to new possibilities. Metasurfaces, the 2D counterpart of metamaterials, may manipulate EM waves in a low-profile manner by using specially designed subwavelength metastructures that have been properly optimized. They're commonly employed to make meta devices like absorbers, holograms, lenses, and sensors. They may change the amplitude, phase, and polarization of EM waves by manipulating the geometric characteristics of the underlying unit cell, and have potential applications including antenna gain enhancement, radar cross-area reduction, and MIMO antenna isolation. Due to their unique properties in polarization manipulation and their potential for rotating EM waves, polarization converters have been extensively utilized in the microwave, terahertz, and even optical frequencies. In many studies, using a metasurface to change the polarization state of EM waves has proven to be a successful method. Realizing a huge bandwidth meta-surface, on the other hand, is difficult and a research topic. As a result, transmission mode and reflection mode metasurfaces are the most often employed research methodologies for implementing the polarization conversion metasurface.

The two-dimensional planar aspect of metamaterial enabled structures has attracted attention in the scientific community towards the construction of polarisation converters with the advent of Frequency Selective Surface (FSS) technology. Furthermore, by stacking multiple layers and high impedance surfaces, the bandwidth can be increased. Cost et al., proposed a dog shaped FSS on top of the grounded substrate which results in linear to circular polarization in the GHz range. Jing et al. proposed a reflective LTC polarization converter with a double-arc-shaped meta-surface which can achieve an efficiency ≥ 80% at a frequency range of 0.59 -1.38Thz with an axial ratio less than 3dB. Lei et al., proposed an ultra-broadband reconfigurable LTC converter which is at a frequency range of 0.69 -1.66Thz range. The polarization states are controlled in transmission mode in most current polarization converters, with only a few devices functioning in reflection mode. The unwanted high co-polarization reflection severely restricts the polarization conversion efficiency and bandwidth of most converters in the reflection mode. Broadband reflective polarization converters with good performance are extremely desirable to enhance the functionality. Many designs for linear-cross polarization conversion (both reflective and transmissive modes) and linear-circular polarization conversions have been found in the literature. But it is rare to get dual-polarization conversion in different frequency ranges in the

THz regime. The proposed unitcell is motivated by the design reported in other literatures, and necessary optimization has done to get dual-polarization conversion at the sub-THz regime.

Aim and Objectives

The aim of this project was to design a reflective type polarization convertor in sub-THz region. To achieve the above aim the following objectives were set

- To verify the hypothesis that the polarization converter is able to achieve linear to linear conversion over three frequency bands and linear to circular conversion over five frequency bands.

Organization of the report

The report is organized as follows: Chapter 2 contains literature review. Chapter 3 elaborates on the design parameters of the unit cell along with the simulation results. Then, the analysis of different polarization mechanisms is detailed in chapter 4.

CHAPTER 2

LITERATURE REVIEW

[1] Liu, Y., Xia, S., Shi, H. et al. Dual-band and high-efficiency polarization converter based on metasurfaces at microwave frequencies. Appl. Phys. B 122, 178 (2016). https://doi.org/10.1007/s00340-016-6454-4

The proposed converter can convert a linearly polarized wave to its cross-polarized wave for two distinct bands: Ku (11.5–20.0 GHz) and Ka (28.8–34.0 GHz). It can also convert the linearly polarized wave to a circularly polarized wave at four other frequencies. The experimental results are in good agreement with simulation results for both frequency bands. The polarization conversion ratio is above 0.94 for the Ku-band and 0.90 for the Ka-band. Furthermore, the converter can achieve dual-band and high-efficiency polarization conversion over angles of incidence up to 45°. The converter is also polarization-selective in that only the x- and y-polarized waves can be converted. The physical mechanism of the dual-band polarization conversion effect is interpreted via decomposed electric field components that couple with different plasmon resonance modes of the structure.

In summary, we have numerically and experimentally demonstrated a dual-band and high-efficiency polarization conversion converter. The converter can convert a linearly polarized wave to a cross-polarized wave for two distinct bands: Ku (11.5–20.0 GHz) and Ka (28.8–34.0 GHz). It also can convert the linearly polarized wave to a circularly polarized wave at four other frequencies. The PCR is above 0.94 in the Ku-band and 0.90 in the Ka-band. Furthermore, the proposed converter can achieve dual-band and high efficiency polarization conversion with angles of incidence up to 45°. The proposed converter also exhibits polarization selectivity with only the x- and y-polarized waves being converted.

[2].A.K.Baghel, S. S. Kulkarni and S. K. Nayak, "Linear-to-Cross-Polarization Transmission Converter Using Ultrathin and Smaller Periodicity Metasurface," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 7, pp. 1433-1437, July 2019, doi: 10.1109/LAWP.2019.2919423.

This article proposes a novel ultrathin linear-to-cross-polarization transmission metasurface converter with a periodicity of 8 mm (λ04.26, where λ0 is free-space wavelength at 8.8 GHz) is proposed, which gives perfect transmission. The proposed MS is a single layer with a thickness of 0.8 mm (0.0235λ0). The conversion efficiency is near unity due to Fabry–Perot resonator-like condition formed, thus giving the perfect cross-polarized wave. The bandwidth of conversion efficiency greater than 80% is 4.21%. As the top and bottom surfaces have the same patterns, the proposed design shows the same conversion with x- or y-polarized incident wave. Due to the ease of fabrication and light weight, the proposed design is a better candidate for applications such as remote sensing and microwave communications than the multilayer transmission converters.

An ultrathin linear-to-cross-polarization transmission MS converter with thickness and periodicity of 0.8 and 8 mm, respectively, is proposed that gives near-unity ηc at 8.8 GHz. Due to the same top and bottom patterns of unit cell, the | Tyx | coefficient does not change with the positive or negative direction of the incident plane wave. For the incident angle less than 30◦, the | Tyx | remains greater than 0.9, and at higher angle of incidence, the peak changes to higher frequency, i.e., 9.1 GHz. This polarizer is very thin, lightweight, and easy to be placed inside the antenna, thus a polarizer converter antenna can be realized.

[3] M. S. Ibrahim, A. Mahmoud, A. Awamry, Z. H. Jiang, W. Hong and M. Al-Nuaimi, "Design and Fabrication of Engineered Reflector for Wideband Linear-to-Circular Polarization Converter," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, 2019, pp. 1697-1698

In this paper, the design of a reflective engineered surface for wideband linear-to-circular polarization (LP-to-CP) conversion is presented. The proposed LP-to-CP polarizer is composed of a symmetric anisotropic unit that has 90° reflection phase difference between its orthogonal reflection components. An LP-to-CP engineered reflector is composed of 14 ×14 unit cells. When illuminated by an x− or y−polarized incident wave, the proposed engineered reflector converts the incident LP wave to a CP reflected wave. The axial ratio (AR) is less than 3dB from 6.9 GHz to 14.1 GHz and the LP-to-CP conversion bandwidth is about 66.6%. The proposed LP-to-CP engineered surface design has been fabricated and it’s being measured now to validate its polarization conversion characteristics at microwave band. The measured results will be presented at the conference.

So, a wideband LP-to-CP converter engineered reflector is proposed and demonstrated by means of full-wave simulation and measurement results. AR (axial ratio) is less than 3dB from 6.9 GHz to 14.1 GHz and LP-to-CP conversion bandwidth is about 66.6%. The proposed surface is being measured now and both simulation and measured results will be presented at the conference.

[4] Q. Zheng, C. Guo and J. Ding, "Wideband Metasurface-Based Reflective Polarization Converter for Linear-to-Linear and Linear-to-Circular Polarization Conversion," in IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 8, pp. 1459-1463, Aug. 2018

In this paper, a wideband metasurface reflector that converts plane wave polarization to cross polarization with a double-square-shaped unit cell is proposed, and the principle of polarization conversion based on polarization synthesis is presented. The proposed structure has a unit cell with a longest dimension of 0.37 wavelengths, a width of 0.23 wavelengths, and a thickness of about 0.09 wavelengths. Using this structure, 95% or more of the incident wave power is converted to cross polarization, covering a fractional bandwidth of 32.4% at 8.5 GHz.

This study proposes a reflector principle that converts polarization by combining radiation from a perturbed DSS element and a BC. The merit of the proposed structure is a simple structure that only one patch layer and one BC layer. The principle of the proposed polarization conversion, which is very simple, is based on synthesizing the polarization from the DSS and that from the BC in a wide frequency range. We have discussed the principle of wideband polarization conversion to cross-polarization. To enhance the bandwidth, we can apply various wideband CP antenna design techniques for wideband polarization conversion [5, 6]. For the infinite periodic structure, 15 dB isolation (conversion efficiency: 97%) was observed between reflected X and Y polarization in a bandwidth of 35.2% (6.8 to 9.7 GHz). Similar performance was measured using a simple measurement setup (bandwidth of 29.4%; 7.25 to 9.75 GHz). The small discrepancy is caused by the transmitting antenna being close to the MSPC to keep a sufficient signal-to-noise ratio in the experiment. In future studies, we will improve this drawback to handle spherical waves or oblique incidence, and further wideband conversion characteristics are expected.

[5] Muhammad Abdul Shukoor and Sukomel Dey , "Wideband Dual-Cut Circular Ring based Linear Cross and Linear-Circular Polarizing Reflector", in IEEE Antennas and Wireless Propagation Letters, vol.22 ,no. 6, pp.978-1-7281-9615-2/20/2020 IEEE

In this paper, a reflective type wideband polarization converter is proposed. It can convert both linear to linear and linear to circular for different frequency bands. It consists of a simple dual-cut circular split ring resonator, printed on a thin FR-4 dielectric substrate terminated with the ground. Simulation result shows, an x/y polarized incident wave conversion to y/x reflected wave in three bands (4.49-4.63 GHz, 7.11-10.75 GHz, 14.94-16.93 GHz) and x/y polarized incident wave returns the circularly polarized reflected wave in three different bands (4.86-5 GHz, 6.09-6.46 GHz, 11.83-14.03 GHz). The proposed structure is compact with a unit-cell periodicity of 0.14λ and overall thickness 0.047λ, where λ corresponds to the lowest frequency of the operational band. The performance of the proposed structure is investigated under different oblique incidences. Surface current patterns are studied to analyze the reason behind the wideband response. Authors strongly believe that the proposed structure has the potential to be used in different applications where both linear-cross and linearcircular conversion are the primary concerns.

In this article, wideband and high-efficiency reflective type polarization converter based on metasurface is demonstrated, which converts the linearly polarized EM wave to its orthogonal, and circularly polarized reflected wave in different frequency bands. A simple dual-cut circular split ring printed on 3.2 mm FR-4 grounded dielectric substrate is used. Fabrication of the proposed metasurface will be done using a traditional printed circuit board (PCB) technology. The compactness of this design, low-profile nature, multipolarization conversion in different frequency bands makes this device to be used many real-time applications where both linear-cross and linear-circular conversion are needed in various bands.

[6]. Rahul Dutta, Jeet Ghosh ,Zhengbao Yang and Xingqi Zhang , "Multi-Band Multi-Functional Metasurface-based Reflective Polarization Converter for Linear and Circular Polarizations",in IEEE Access, October 26,2021-Vol.9-10.1109/ACCESS.2021.3128190

In this paper, we present a simple metasurface based multiband reflective polarization converter for both linear and circular polarizations. We show that, on one hand, the proposed structure can convert the polarization of linearly polarized waves to the orthogonal direction at four frequency bands — 4.3 GHz, 7.2 GHz, 12.3 GHz, and 15.15 GHz. On the other hand, this metasurface can achieve linear to circular or circular to linear polarization conversion at 4 GHz, 4.75–5.95 GHz, 8.35–8.8 GHz and 14.35–14.6 GHz frequency bands. Such multiband operation originates from multiple resonances occurring in the structure based on meandered square ring and diagonal split strip resonator. Moreover, the polarization transforming capability is stable for oblique incident angle up to 15o, for both transverse electric (TE) and transverse-magnetic (TM) polarizations. Furthermore, the proposed structure acts as a meta-reflector that maintains the handedness of the circular polarization upon reflection. Finally, a prototype of the proposed meta-structure is fabricated and measured for both normal and oblique incidence of electromagnetic waves. All the results present excellent resonant stability with respect to the different polarization and incident angles. In addition, we have also performed the tolerance analysis of different material parameters to understand the robustness of the structure. Due to the ability of the structure to perform three functionalities through a single layout, the proposed design can pave its way in different microwave applications such as satellite, radar, and 5G communications.

In summary, we have realized a planar metasurface based multiband reflective polarization converter for both linear-to-linear and linear-to-circular or circular to linear polarization transformation. Due to the anisotropic characteristic of the metasurface, the proposed structure can convert a y/x-polarised incident electromagnetic wave to an x/y-polarised reflected electromagnetic wave in four frequency bands with PCR over 95%. Further, the metasurface can also convert an LP incident wave into a circular configuration in another four frequency bands with less than 3 dB axial ratio. The proposed octa-band reflective polarization converter is made up of meandered square split ring resonator and diagonal strip structure, which gets multiple resonances, enabling the metasurface to achieve polarization transformation in multiple bands. Parametric studies and analytic derivatives with respect to the different parameters are given in details to serve as a guide for the design. Moreover, a step-by-step design procedure is explained for providing an insight in the design procedure. A study of the induced surface current distributions along with a rigorous theoretical analysis is presented to explain the operating principle of the polarization conversions. This reflective polarization converter structure covers most of the C,X and Ku bands. All the simulation results are verified through experimental measurements.

[7]. R.M.H. Bilal, M.A. Baqir, P.K. Choudhury, M.M. Ali, A.A. Rahim, On the specially designed fractal metasurface-based dual-polarization converter in the THz regime, Results in Physics, Volume 19, 2020, 103358, ISSN 2211-3797

In this paper,a specially designed fractal metasurface-based structure was investigated as a dual-polarization converter operating in the terahertz(THz) band. The proposed converter has the ability to perform both the linear-to-cross (LX)and linear-to-circular(LC) polarization conversions. In the former kind of operation, it exhibits three unity polarization conversion ratio(PCR) peaks at 1.10THz, 2.13 THz and 3.46THz frequencies, where as in the latter situation, the conversion was achieved over three operating bands, namely 1.2–1.83THz,2.52–3.10THz and 3.78–3.90 THz. The effect of oblique incidence on the performance of metasurface (used in designing the converter) was also studied, and fairly stable operation could be determined. The obtained results indicate the proposed converter to have possible potentials in imaging, antenna engineering and certain other photonic devices used in the fields of medical diagnostics, sensing ,and other related measurements.

The afore discussed results indicate that the proposed fractal metasurface-based polarization converter can perform both the LX and LC kinds of conversion in the THz regime of EM spectrum. To be more specific, it converts the linear x-polarized THz wave into its cross components with three different operating points as 1.10 THz, 2.13 THz and 3.46 THz with a PCR of unity. It also exhibits the LC polarization conversion with three different wideband operating frequencies, namely 1.2–1.83 THz, 2.52–3.10 THz and 3.78–3.90 THz. The study of the effect of incidence obliquity shows that the increase in incidence angle results in very small amount of blue-shift of the operating bands. Nevertheless, the proposed structure exhibits fairly good angular stability in the polarization conversion operation. Such broadband polarization converter with high PCR and fairly good stability against incidence obliquity remains of great potentials in many EM applications that include antenna engineering, photonic communications and other THz applications.

[8] Yannan Jiang, Lei Wang, Jiao Wang, Charles Nwakanma Akwuruoha, and Weiping Cao, "Ultra-wideband high-efficiency reflective linear-to-circular polarization converter based on metasurface at terahertz frequencies," Opt. Express 25, 27616-27623 (2017)

The polarization conversion of electromagnetic (EM) waves, especially linear-to-circular (LTC) polarization conversion, is of great significance in practical applications. In this study, we propose an ultra-wideband high-efficiency reflective LTC polarization converter based on a metasurface in the terahertz regime. It consists of periodic unit cells, each cell of which is formed by a double split resonant square ring, dielectric layer, and fully reflective gold mirror. In the frequency range of 0.60 – 1.41 THz, the magnitudes of the reflection coefficients reach approximately 0.7, and the phase difference between the two orthogonal electric field components of the reflected wave is close to 90° or –270°. The results indicate that the relative bandwidth reaches 80% and the efficiency is greater than 88%, thus, ultra-wideband high-efficiency LTC polarization conversion has been realized. Finally, the physical mechanism of the polarization conversion is revealed. This converter has potential applications in antenna design, EM measurement, and stealth technology.

In this study, an ultra-wideband and high-efficiency LTC reflective polarization converter is designed based on a metasurface at terahertz frequencies. Due to the multiple resonance characteristic in the proposed design, the ultra-wideband can be obtained. For the two orthogonal electric field components of the reflected wave, the magnitudes of the reflection coefficients are approximately equal and as high as 0.7, and the phase difference is close to 90° or –270° from 0.60 to 1.41 THz (i.e., RBW ≈80%) when the incident wave is y-polarized. This results in ultra-wideband and high-efficiency LHCP. There is also a narrowband RHCP in the range of 1.48–1.54 THz. The converter can operate in LTC polarization conversion with an opposite rotation under x-polarized incident wave. With the increase in angle of incidence, the design can operate in one ultra-wideband and one narrowband, one wideband and two narrowbands, and just one narrowband. The LTC converter can be used as a key component in applications of EM measurement, antenna design, and stealth technology.

[9] M. A. Shukoor and S. Dey, "Broadband Linear-Cross Reflective type Polarization Converter for X and Ku-band Applications," in Proceedings of the 2020 International Symposium on Antennas and Propagation, APSYM 2020, pp. 93–96, Dec. 2020.

This paper presents a novel linear to cross reflective type polarization converter for X and Ku-band applications. It comprises a 45° tilted resonating patch on the top of a thin FR-4 substrate, which is terminated by PEC on the other side. The converter exhibits Polarization Conversion Ratio (PCR) greater than 90% over 10.17 GHz bandwidth (from 8.2 to 18.37 GHz) with 76.5% fractional bandwidth (FBW). Multiple surface plasmonic resonances are responsible for uniform PCR over the broadband. The reason behind the ideal response at resonant frequencies is illustrated by surface current distribution analysis. This design is obliquely stable up to 30°, with a minimum of 87% PCR, for the transverse electric (TE) mode and the same is observed for transverse magnetic (TM) case. The proposed linear-cross converter is compact with periodicity 0.213λLand thickness 0.07λL, where λLcorresponding to the free-space wavelength of lowest bandwidth frequency. RCS analysis has been performed for monostatic and bistatic cases to demonstrate the capability of the proposed design in EM shielding applications

The structure is made of a simple resonating patch printed on the grounded dielectric substrate. It shows stable perfor-mance up to 30° for both oblique incidences (TE and TM). The usefulness of the proposed design has been elucidated for monostatic and bistatic RCS reduction. In addition, manufacture and comprehensive characterization will be done in future. Compactness and angular stability response of the proposed structure would be useful to meet real-time needs. The authors believe that this design is useful in multiple application where the linear- cross polarization conversion is our primary concern

CHAPTER 3

SOFTWARE USED

Ansys HFSS Electronics Desktop

Fig.1 Ansys HFSS Logo

Ansys HFSS (high-frequency structure simulator), is a commercial finite element method solver for electromagnetic (EM) structures from Ansys that offers multiple state-of-the-art solver technologies .Each solver in ANSYS HFSS is an automated solution processor for which the user dictates the geometry, properties of the material and the required range of solution frequencies.

Ansys Electronics Desktop is a comprehensive platform that enables electrical engineers to design and simulate various electrical, electronic and electromagnetic components, devices and systems. It is a unified interface that creates and analyzes electromagnetic (EM), thermal and circuit designs. This software was developed by Ansoft Corporation, which was acquired by Keysight Technologies in 2014. Keysight continues to develop and sell HFSS today

Engineers can access gold-standard tools such as Ansys HFSS, Ansys Maxwell, Ansys Q3D Extractor and Ansys Icepak using electrical CAD (ECAD) and mechanical CAD (MCAD) workflows. In addition, the Electronics Desktop includes direct links to the full Ansys portfolio of thermal, fluid and mechanical solvers for comprehensive multiphysics analyses. Engineers can integrate rigorous 2D and 3D physics analyses with system and circuit simulations, all inside a single framework called Ansys Electronics Desktop. Any combination of products within the Electronics Desktop can be inserted into a single project. For instance, you can combine disparate design types such as HFSS, Circuit and Icepak into a single project. HFSS is a finite element method (FEM) software used for electromagnetic field simulation. It models the interaction of electromagnetic fields with arbitrary three-dimensional (volumetric) objects having complex shapes, materials, and ports. HFSS is widely used in the design of high-frequency electronic components such as antennas, RF & microwave circuits, and packaging. By understanding how HFSS works, engineers can design better systems and products that make use of electromagnetic waves. Two main types of simulations can be performed using HFSS: transient and steady-state. In a transient simulation, the electromagnetic fields are time-varying, while in a steady-state simulation, the fields are constant in time. One advantage of using HFSS is that it can be used to simulate a wide variety of electromagnetic phenomena. Some of the phenomena that can be simulated using HFSS include:

- Transmission and reflection of waves

- Scattering

- Diffraction

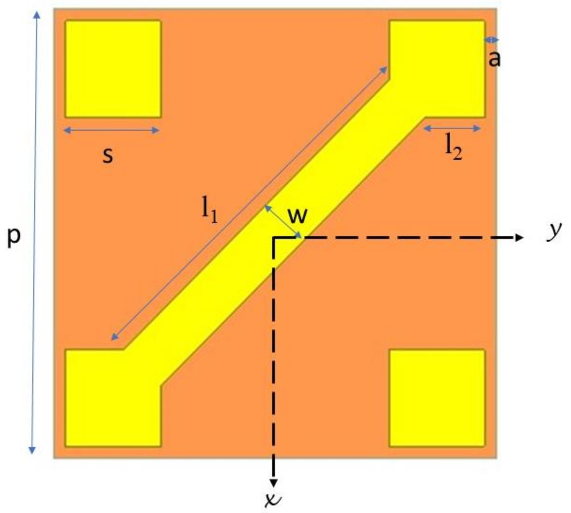
- Radiation and absorption

Additionally, HFSS can be used to optimise the design of high-frequency components. HFSS is more accurate than CST but it takes longer to run simulations. CST is not as accurate as HFSS but it is faster in terms of simulation speed

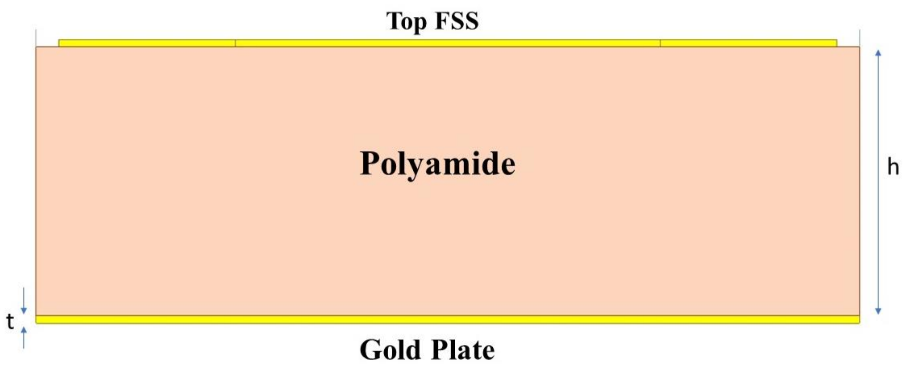
CHAPTER 3

METHODOLOGY

The proposed design is a reflective type of ultrawideband polarization convertor, and its response is documented. A schematicc of the unit cell of the proposed polarization convertor is shown in Fig.1(a). The converter is capable of both linear to linear, and linear to circular polarization conversion simultaneously in multiple frequency bands at the sub-Terahertz frequency range. Multiple surface plasmonic resonance is the reason behind the multi-polarization conversion behavior.



(a)



(b)

Fig.1. (a) The top view and (b) side view of the proposed unit cell.

3.1 DESIGN AND SIMULATION OF UNIT CELL

3.1.1 DESIGN PARAMETERS OF UNIT CELL

The proposed polarization converter consists of a four-square patch at each edge with a rectangular patch joining them diagonally. The top FSS is replicated on the upper surface of the polyamide substrate, which has a thickness of 28µm, a relative permittivity of 4.3, and a dielectric loss tangent of 0.004. On the other side, the substrate is terminated with the ground The top FSS and ground metallic layers are made of an 800nm thin gold film with a conductivity of 4.1 107 S/m. The proposed cell's optimum parameters were calculated using ANSYS HFSS, a Finite Element Method (FEM) based EM solver. In the azimuthal plane and floquet port along the z-direction, master-slave Periodic Boundary Conditions (PBCs) are used. The unit-finalized cell's dimensions are p = 86 µm, s = 18.5 µm, w = 10 µm and a = 2.3 µm, l_1=72.7 µm, l_2 =11.4 µm as shown in Fig. 1. Here, p represents the periodicity of the unit cell, s is the width of the square, w represents the width of the rectangular bar, and a represents the distance between the cell and square.

3.1.2 SIMULATION USING ANSYS HFSS

The proposed unit cell is generated using a Finite Element Method based (FEM) solver based ANSYS HFSS. There are various steps for simulation in ANSYS HFSS.

1. GEOMETRY OF UNIT CELL

   A unit cell is designed with the parameters mentioned above.

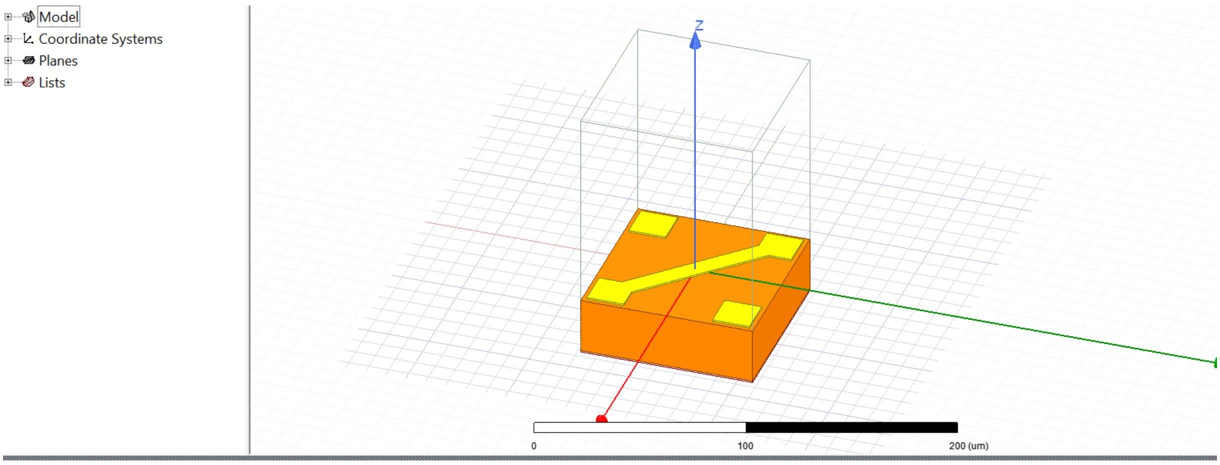
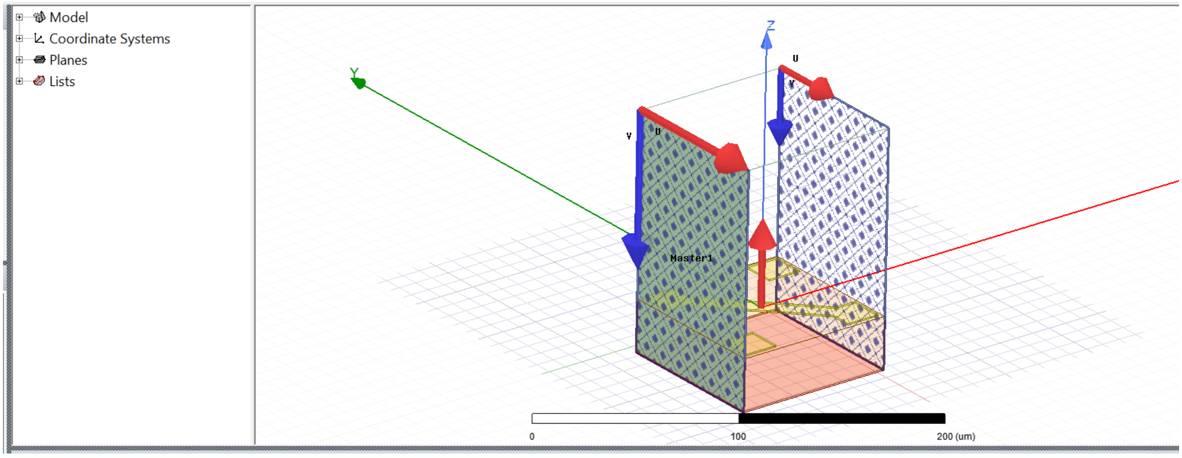


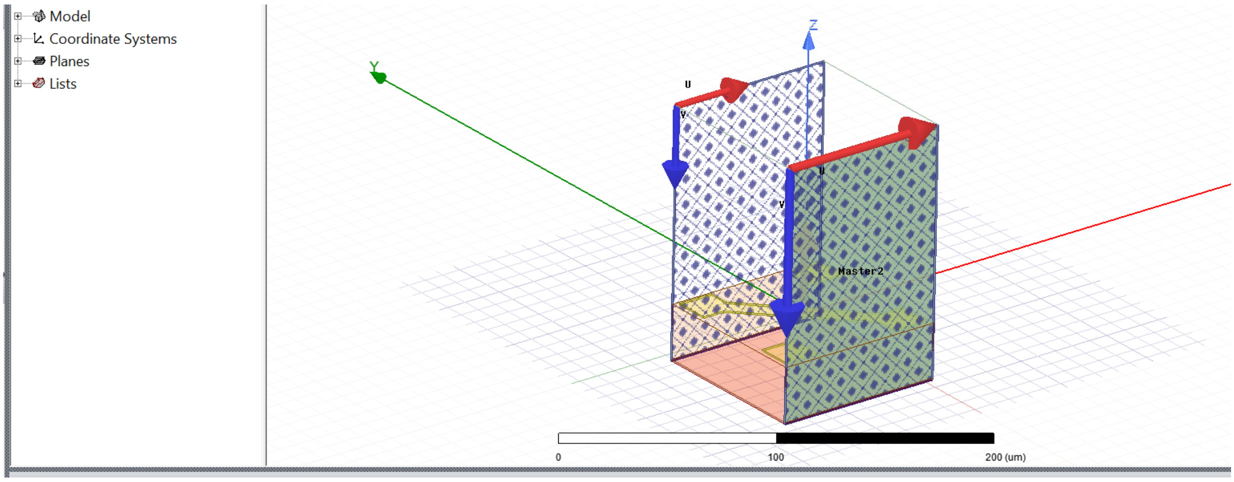
Fig. (2) Geometry of Unit cell.

2. BOUNDARY CONDITIONS

Boundary conditions are assigned by assigning the master-slave boundary condition. Master-slave boundaries are used to model unit cell of periodic structures. Master and save boundaries are always paired. Fields on the master surface are mapped to the slave surface with a phase shift enforcing a periodicity in the fields.



(a)



(b)

Fig. (3) Master-slave boundaries are applied. (a) Master 1. (b) Master 2.

3. EXCITATION

Floquet port excitation is given on the top face. Floquet port is used to excite and terminate waves propagating down the unit cell. These are always linked to master or slave boundaries. Floquet port is only used for surfaces exposed to the background. It also replaces radiation boundary and PML for free space field absorption. Floquet port decomposes the fields into floquet modes i.e., Set of TE and TM modes in which the power travels.

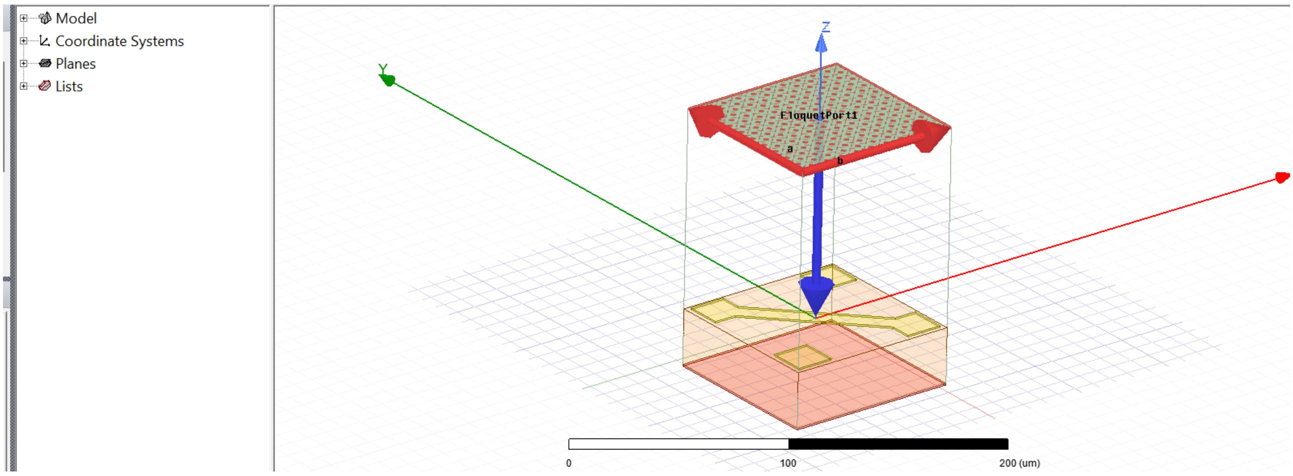


Fig. (4) Excitation of unit cell using Floquet port.

CHAPTER 4

RESULTS AND DISCUSSION

Let us consider a y-polarized EM wave incident on the metasurface. To begin with, the co pol reflectance and cross-pol reflectance is determined. Co-polarized refers to identical transmit and receive polarization states such as HH and VV. Cross polarization refers to transmitting in one polarization state and receiving in the orthogonal polarization state. One can define the cross-pol reflectance $r_{xy} = \overrightarrow{|E_x^r|} / \overrightarrow{|E_i^y|}$ and co-pol reflectance $r_{yy} = \overrightarrow{|E_r^y|} / \overrightarrow{|E_i^y|}$. Here, $\overrightarrow{E_i}$ and $\overrightarrow{E_r}$ are the incident and the reflected field components. The indices x, y indicates the direction of the field component. The efficiency of the polarization conversion from linear to its orthogonal component can be obtained by the Polarization Conversion Ratio (PCR), $\eta = r_{xy}^2 / (r_{xy}^2 + r_{yy}^2)$. The simulated co-pol and cross-pol reflectance in terahertz frequency regime are given in fig. (5).

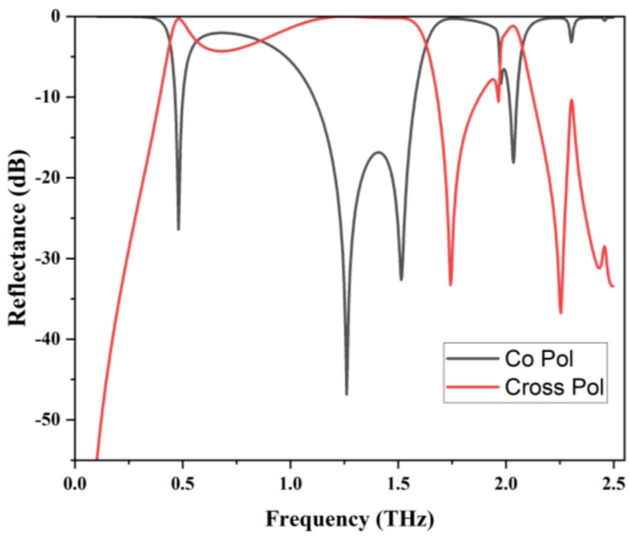


Fig. (5) Cross-pol and co-pol reflectance of the proposed convertor in terahertz frequency.

Fig. (5) depicts that the seems that there are a total of five co-pol reflection dips with near 0 dB cross-pol reflection coefficient. Moreover, the cross-pol reflectance approaches near 0dB, which results near unity polarization conversion as shown in fig. (5).

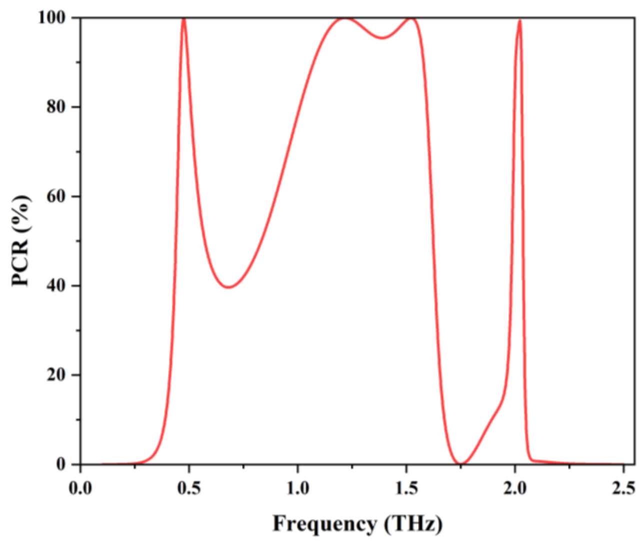


Fig. (6) PCR response of the proposed polarization convertor in terahertz frequency.

From fig. (6) depicting the PCR response, we can notice that there are multiple resonances at frequencies 0.479 THz, 1.211 THz, 1.515 THz, and 2.016 THz, showing the PCR such as 99.77%, 100%, 99.92%, and 98.56%, respectively. The PCR is greater than 90% for three wide bands from 0.46- 0.50 THz (with 0.04 THz bandwidth), 1.08-1.57 THz (with 0.49THz bandwidth) and 2.0-2.02THz (with 0.02THz bandwidth. The PCR is nearly 50% in three frequency regions (0.44-0.57 THz, 0.83-1.62 THz and 1.98-2.05 THz), implying that only 50% of the energy is transformed into its orthogonal direction.

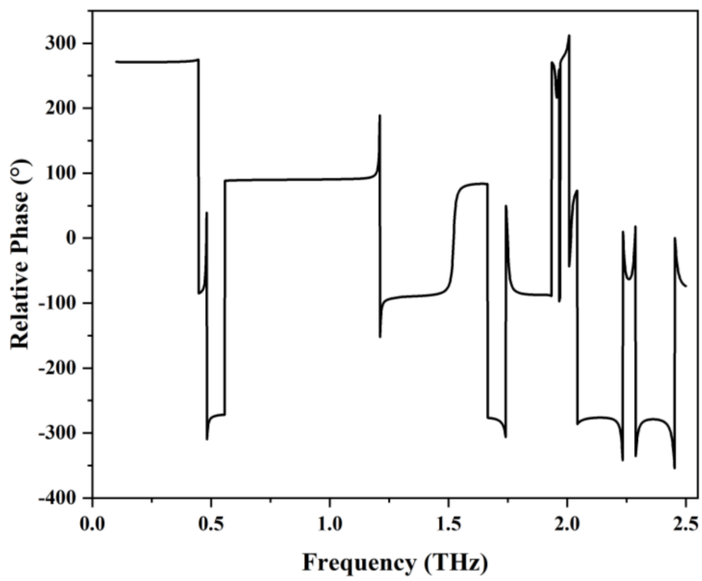


Fig. (7) Relative phase of the proposed polarization convertor in terahertz frequency.

To analyze the ability of circular polarization conversion, the relative phase shift ($\Delta\Phi$) between the components is calculated, as shown in fig. (7). The relative phase shifts of the scattered waves, which arrive at the observation point, reflect the relative variation in distance of the scattering nuclei from the observation point, and thus these relative phase shifts in the amplitude, provide the shape and dimension of the crystal. justified. The relative phase between co-pol and cross-pol reflectance in terahertz frequency range is determined and its response is depicted in Fig. (7). Here, from 0.53 THz- 0.94 THz, = +90°, 1.61 THz – 1.64 THz = +90° and from 2.04 THz to 2.06 THz, = −270° (= +90°), which implies the reflected wave is Left Hand Circularly Polarized (LHCP) for the y-polarized incidence.

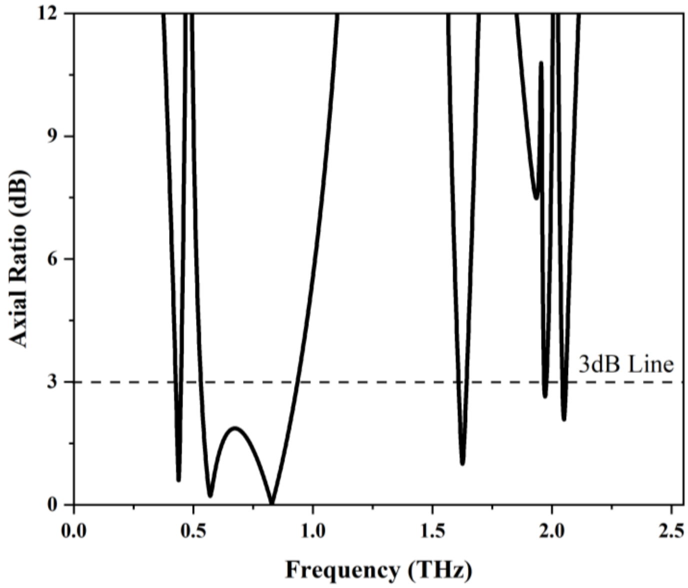
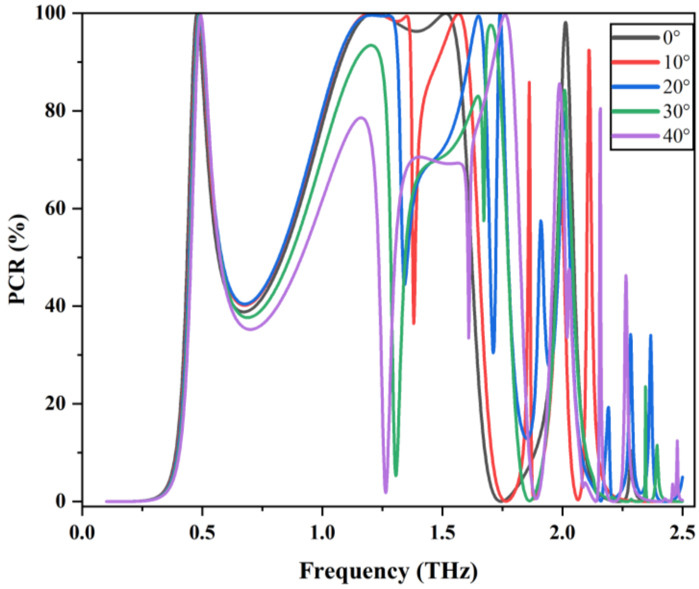


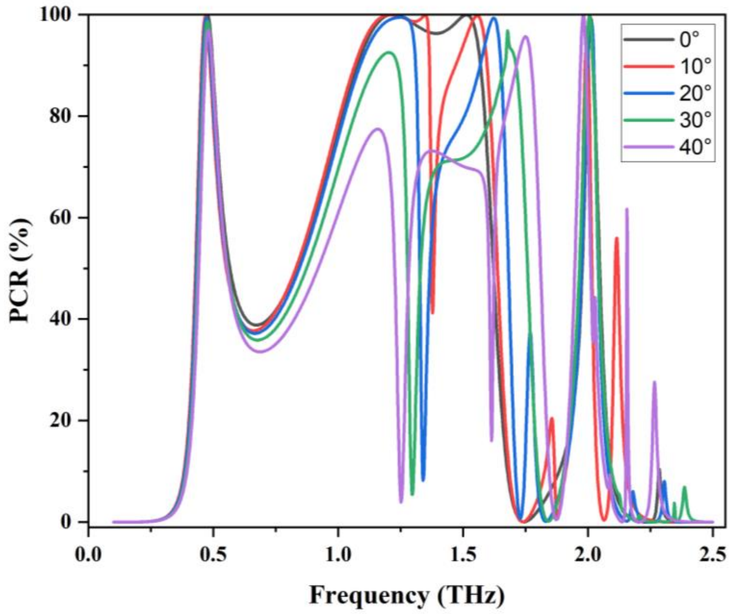
Fig. (8) Axial ratio of the proposed polarization convertor in terahertz frequency.

The linear-circular conversion is determined by the factor Axial Ratio (AR). For the reflective type polarization converter, AR is calculated, and the simulated axial ratio is depicted in Fig. (8). The axial ratio is the ratio of orthogonal components of an electric field. A circularly polarized field is made up of two orthogonal electric field components of equal amplitude (and 90 degrees out of phase). Because the components are of equal magnitude, the axial ratio is 1 (or 0 dB). The axial ratio for an ellipse is larger than 1(> 0dB). The axial ratio for pure linear polarization is infinite because the orthogonal component of the field is zero. Axial ratios are often quoted for antennas in which the desired polarization is circular. The idea value of the axial ratio for circularly polarized fields is 0dB. In addition, the axial ratio tends to degrade away from the main beam of an antenna, so the axial ratio may be indicated in a data sheet for an antenna as less than 3dB (< 3dB). This indicates that the deviation from circular polarization is less than 3dB over the specified angular range. The axial ratio is also calculated to determine the strength of circular polarization.

Fig. (8) shows the simulated axial ratio for the reflective type of polarization convertor in terahertz frequency range. The proposed polarization converter shows less than 3 dB AR in five different frequency ranges, 0.43-0.45 THz, 0.53-0.94THz, 1.61-1.64 THz, 1.96-1.99 THz and 2.04-2.06 THz. Also, the polarity of the circularly polarized wave is defined.



(a)



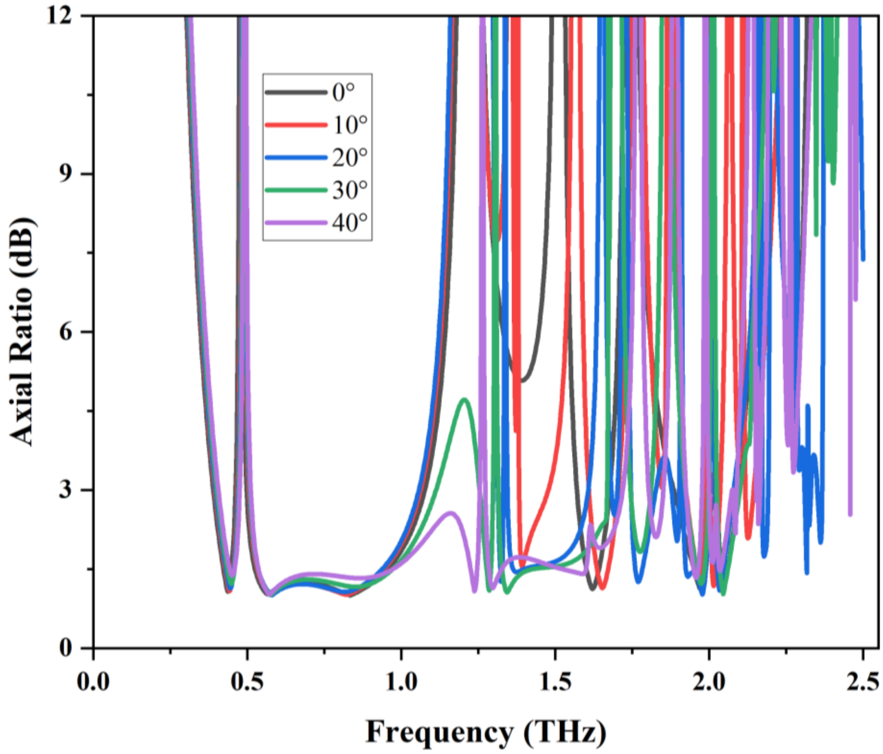
(b)

Fig. (9) Variation in the PCR under different oblique incidences in (a) TM mode. (b) TE mode.

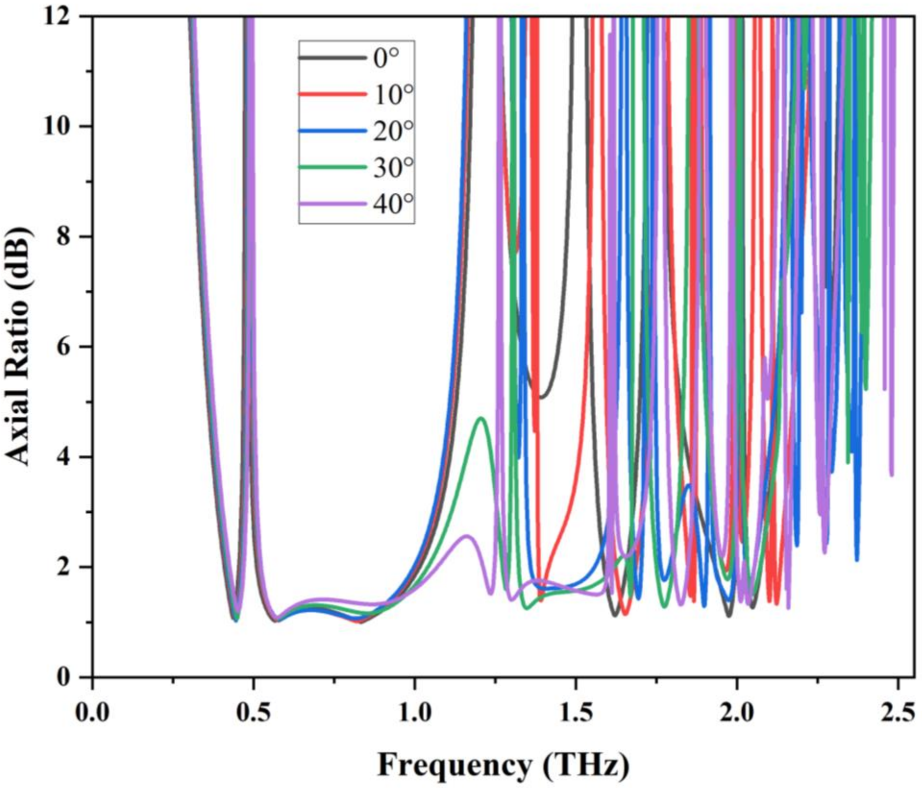
In this section, the dissimilarity in the performance of the proposed polarization converter under different oblique incidences for Transverse Electric (TE) and Transverse Magnetic (TM) modes are analyzed. The simulated PCR for TE and TM incidences are shown in Fig. (9).

From Fig. (9), it is observed that the proposed design is showing stable 90% PCR response up to 40° for both TE and TM incidences with the negligible bandwidth reduction. But it shows considerable disturbance in between the bands (circular polarization section) for both TE and TM.

The dependence of the axial ratio for oblique incidence in TE and TM modes is studied in Fig. (10), which depicts that the axial ratio is more sensitive with the incident angle. From the above response, this design is stable up to 40° for linear-cross conversion and up to 30° for linear-circular conversion.



(a)



(b)

Fig. (10) Axial ratio dependence for different oblique angle under (i) TE mode (ii) TM mode

The response of the axial ratio is simulated by keeping 10^o steps from 0 to 40^o. It shows a stable less than 3 dB axial ratio up to 30^o.

CHAPTER 5
CONCLUSION

In this report, the demonstration of a wideband high-efficiency reflective type metasurface-based polarization converter is demonstrated. This design can convert linearly polarized wave into its orthogonal component and circularly polarized wave, respectively, in different frequency bands in the sub-Terahertz range. The simulation results depict that the design achieves greater than 90% PCR and 3 dB AR in different frequency regions. We have verified the hypothesis that the metamaterial-based polarization converter is able to achieve linear to circular conversion over five frequency bands in the sub-THz frequency ranges. The micromachining method will be used to fabricate the proposed design, and the performance parameters will be measured. The various advantages of this design include compactness, low-profile nature, and the ability for multiple polarization conversions make this device suitable to be utilized in many real-time applications where both linear-cross and linear-circular conversion are required in various frequency bands.

FUTURE SCOPE

Electromagnetic waves play an important role in the field of modern communication engineering, and people are increasingly hoping to achieve perfect control of electromagnetic waves with devices such as polarization converters, lenses, and phase modulators. The amplitude and phase control are greatly developed in devices such as amplifiers and power dividers, and metasurfaces. The regulation of polarization, however, is still insufficient and can be further developed. Future communication systems will be based on multiple polarization devices to exchange information, so polarization control is essential. Compared with traditional polarization control devices based on dichroic crystals and birefringent materials, metamaterials present exotic properties, such as a lighter, smaller, and simpler design. More recently, metasurfaces have emerged as promising alternatives to conventional polarization manipulation components because the flexibility of their geometry means that they can be arbitrarily customized. It has great potential for applications in polarization-controlled devices and is believed to be extendable to higher frequency regimes. The two-dimensional metamaterial, i.e. meta-surface, has a thickness that is much smaller than the wavelength, and at the same time, has remarkable electromagnetic properties.

The proposed metasurface should have a great potential in sensor applications,imaging systems, radiometers, stealth technology, electromagnetic measurements, and antenna design because of its ultra-wideband, highly efficient and dual band performance

Radar Cross Section (RCS) of an object is the effective area that can be seen by the radar. Since the metallic conductors perfectly reflect all the incident EM energy, RCS is more for the metallic object. Hence, the reduction of Radar Cross Section (RCS) from metallic targets is the main objective in military and defense applications. It can be reduced in many ways, but using a planar polarizer reduces the design complexity and make it compact.

Wave plates are some of the most ubiquitous components in optics. Most commonly used designs are based on bulk birefringent crystals with optical anisotropy. This conventional approach has several limitations: it is relatively narrow band, and it relies on the availability of birefringent materials in the desired frequency range. Approaches exist to overcome the latter limitation, which utilize form birefringence of anisotropic structures such as plasmonic antennas. These come with their owning particular, they exhibit relatively low purities of polarization and often superimpose an optical background onto the desired signal. In addition, the bandwidth of these devices is also relatively small.

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