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Frequency Selective Surface as Microwave Polarizer

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Abstract:
In this project we proposed a microwave polarizer constructed on a FR4 substrate. The polarizer is made up of Frequency Selective Surface (FSS) with U- shaped resonator and working in the low frequency applications is proposed. The proposed polarizer gives a response of dual linear polarization filtering at 2.45GHz and 5GHz. The polarizer has a structure consisting of single layer with unit elements of varying sizes. In the single layer of the polarizer is a U-shaped resonator serving as the unit element. The microwave polarizer that will be used for this project will be mounted on a FR4 substrate that is cost effective and has excellent mechanical properties. The proposed design has several advantages, such as easy to implement, low profile, high bandwidth, frequency of operation, and relative insertion loss. We are using HFSS (High Frequency Structure Simulator) to configure a simulation of an FSS polarizer that can be used for microwave oven and 5G communication applications.

***Key Word**: Frequency Selective Surface, Polarizer, U-shaped resonator*

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I. Introduction

The polarization of waves has become a topic of interest in the past years, particularly in linearly polarized (LP) and circularly polarized (CP) waves [1]. LP filtering involves filtering out the cross-polarization component of a plane wave while leaving the co-polarization component intact [2]. Another area of interest is the conversion of linear to circular polarization (LCPC) which is important for communication systems and sensor networks that are sensitive to propagation effects such as multipath fading and reflections. To achieve CP plane waves, frequency selective surfaces (FSSs) are used which are 2D periodic surfaces created by translating a fundamental spatial component in two different orientations. Typically, translations in a plane along two orthogonal lines are used [3]. When designing FSSs for filtering or selective screening, it is desirable to maintain symmetry in order to achieve insensitivity to polarization. However, processing polarization requires waves to travel through an anisotropic medium, which reduces the number of symmetries the surface can exhibit.

According to [4], an early linear-to-circular polarization converter has been developed using twisted metal lines on a surface. The polarizer was implemented in both planar and cylindrical versions. However, the construction of the polarizer required several layers for proper operation, which resulted in a bulky device and limited its practical use. This information is consistent with what was mentioned in [2] about the challenges associated with the construction of LCPC polarizers.

Multiple-layer LP-CP converters have been proposed by many authors. [5] presents a polarizer structure that can reflect Linearly Polarized waves as Circularly Polarized waves at a specific frequency while being transparent at other frequencies. The structure consists of two parallel surfaces with unit cells constructed around dipoles. The dipoles on one surface are placed orthogonally to the dipoles on the other surface. This arrangement enables the structure to convert the polarization of the incident waves efficiently.

A dual-band LP-CP converter is presented in [6] that can convert LP waves into transmitted RCP or LCP waves depending on the frequency of the incident waves. The unit cell design comprises three metallic layers consisting of metallic patches, a split ring, and a circular slot. The structure is designed to operate in the K/Ka satellite communication band.

[7] describes a dual-band LP-CP converter that utilizes a four-metal layer structure separated by dielectric layers. The unit cells consist of split-ring resonators bisected by metal strips, rectangular patches, and rings. The polarizer is designed to operate in the range of 6.4 - 8.8 GHz and 12.1 - 13.9 GHz frequency bands.

In [8], an FSS has been developed and demonstrated to work as a polarization converter for the frequency range of X band. The FSS utilizes unit cells based on slot-line that are stacked in two orthogonal directions in a multi-layer 3D structure. Furthermore, a dual-band polarizer for the K/Ka band has been created by layering two similar metal layers with patterns consisting of a Jerusalem cross and linear dipole [9].

[10] reports on a tunable converter that operates in the terahertz frequency range and comprises two layers of metal and graphene resonators separated by a dielectric layer. The tunability is achieved through the ability to regulate the Fermi energy of the graphene material.

For high gain the high impedance technique has emerged as a modern approach which minimizes surface waves and provides increased gain by using fractal geometry high impedance surface. Hilbert curve-based fractal geometry minimizes physical length and keeps electrical length same [18].

Given the widespread interest in the subject, we concentrate on a single-layer FSS based polarization processing surface that is affordable, simple to construct, and scalable. We describe a multi-functional FSS that can be used for the operations mentioned below for the polarization processing:

- At a different frequency, it can transmit linearly polarized waves in one direction while filtering out the linearly polarized waves in an orthogonal direction;
- At a middle frequency, it can transform linearly polarized waves into circularly polarized waves at an angle of 45^0.

The unit cell we looked at has a very basic structure that is made up of a U-shaped resonator on top of a FR4 substrate.

II. Simulation Results of Unit Cell

Unit Cell Representation:

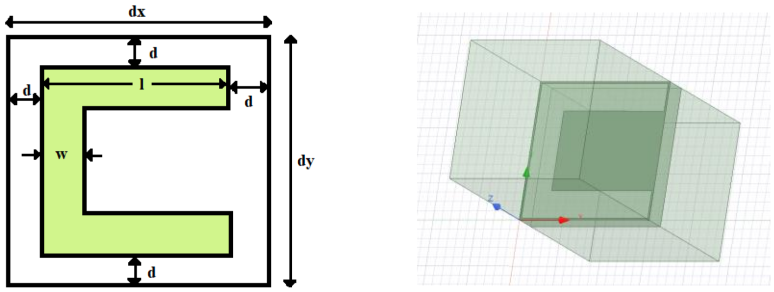

Fig 1(a) Fig 1(b)

Fig 1: Unit cell front view and CAD model

The FR4 substrate used in the construction of the periodic surface has a thickness of 2.4 mm. At the frequency range being considered, the short-wavelength path through the dielectric means that the thickness value has a minimal impact on how the structure interacts with incident electromagnetic waves. The U-shaped metal pattern's equal arms are equally spaced from each of the unit cell's boundaries by a distance of d. The trace width, w, is also an equally significant characteristic. The simulated structure has dimensions of dx=dy=15 mm, w=0.2 mm, l=14.6mm and d=0.2 mm.

Simulation Results at Normal Incidence:

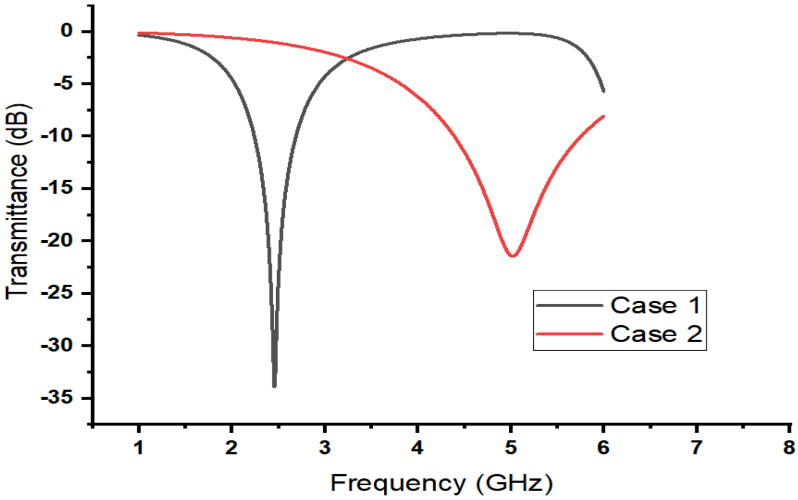

Fig 2(a): Transmission Coefficient

In the above figure the curve indicated as "Case 1" represents the results of C shape while "Case 2" represents the U shape. From the above-mentioned fig. 2(a), we can observe that the dual linear polarization filtering output of our proposed FSS loaded with U-shaped resonator operating at f=2.45GHz to f=5GHz. So, in addition to the low frequency applications, we find another specific application where our proposed FSS loaded with U-shaped resonator works flawlessly. At frequency f=5GHz, the polarizer finds a specific usage as an FSS polarizer, which is applicable to microwave ovens and 5G communications.

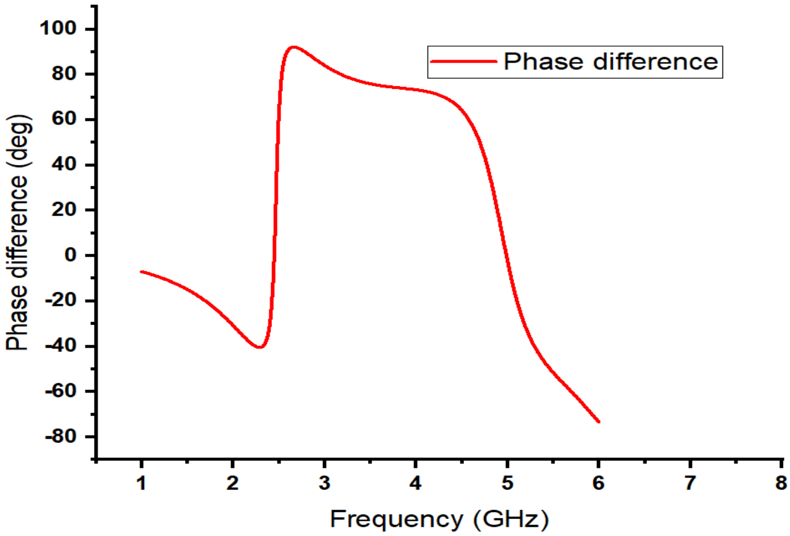

Fig 2(a): Phase difference between C and U shape

According to the above-mentioned results, the phase difference at frequency f=2.68 GHz is extremely close to 90^0. The determination of circular polarization and perception of rotation at the output is based on the phase difference between the two axes while considering that the wave is travelling along the other axis.

From the above simulated results, we got transmittances T1 = -33.89 and T2 = -21.39 for frequency f1 = 2.45 GHz and f2 = 5 GHz respectively.

III. Parametric Analysis

Varying Length:

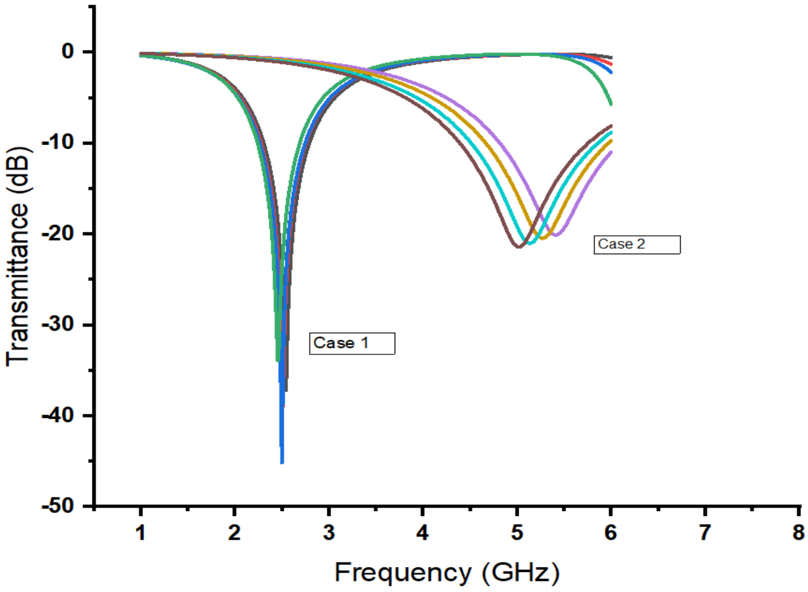

Fig 3(a): Transmission coefficient response for varying length

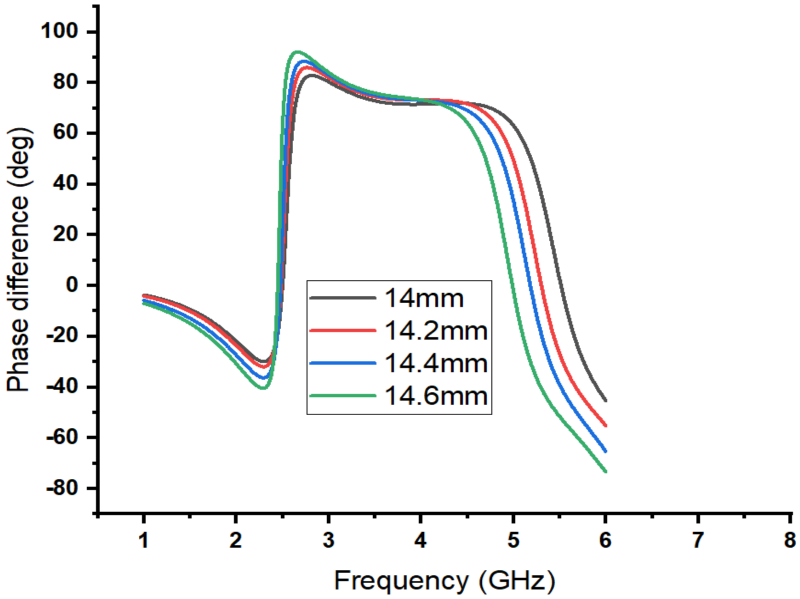

Fig 3(b): Phase difference response for varying length

This operation is performed to study the effect of varying the length on the proposed polarizer design. This study aims to verify our proposed microwave polarizer characteristics for different variations and understand polarizer's stability and correctness. Varying length of the unit cell doesn't significantly differ in operating frequency in response to polarizer. It has a minimal effect but the changes in length affects in case 2 while case 1 characteristics remain unaltered. It is observed that variation in length from 14.6mm to 14mm shifts operating frequency from 5 GHz to 5.4 GHz. The phase difference also doesn't significantly change.

Varying Thickness:

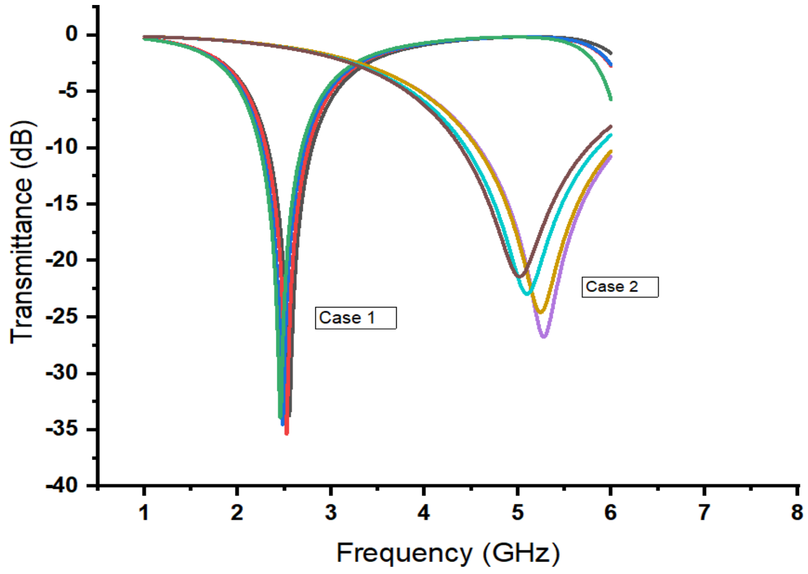

Fig 4(a): Transmission coefficient response for varying thickness

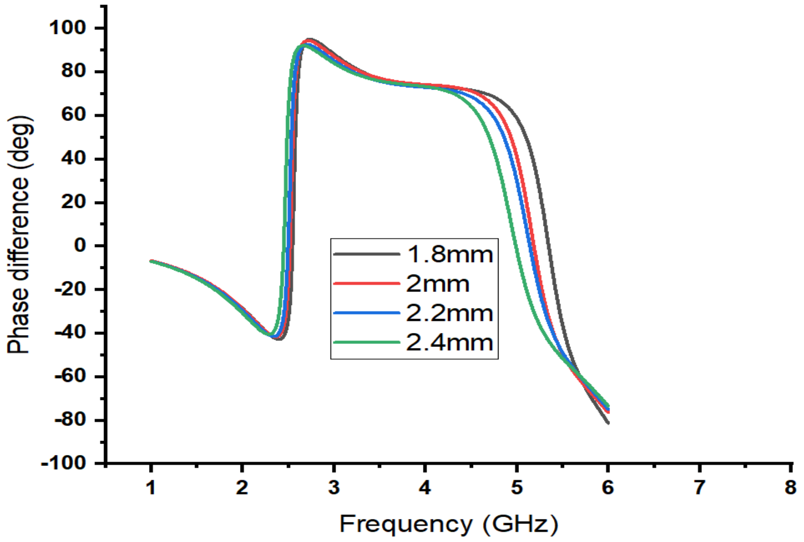

Fig 4(b): Phase difference response for varying thickness

In this parametric variation, we study the effect of variation in substrate thickness. Procedurally the Thickness of a substrate is reduced. In this operation, the effect of the thickness of the substrate has a considerable change in operating frequencies. The variation in thickness of the substrate results as a decrease in thickness results is an increase in operating frequency. For t = 2.4mm to 1.8mm there is a variation of operating frequency from 2.45 GHz to 2.54 GHz in case 1 and 5 GHz to 5.27 GHz in case 2. Overall, the effect of thickness variation is minimal for both transmission coefficient and phase difference responses.

Varying Incidence angle theta(θ):

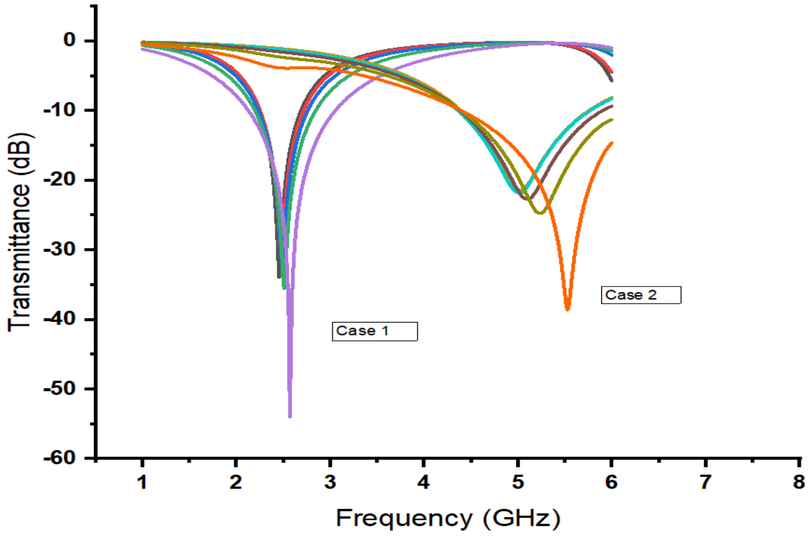

Fig 5(a): Transmission coefficient at oblique incidence ($ø=0^0$)

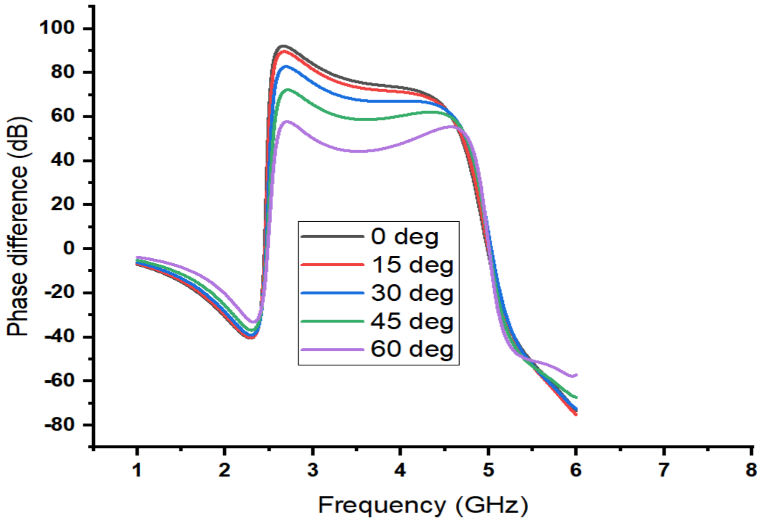

Fig 5(b): Phase difference at oblique incidence ($ø=0^0$)

The reported figures shows that the FSS polarizer shows an accurate response with minimal loss for various incidences. It is also observed that an angle of incidence $\theta = 0^0$ to $\theta = 60^0$, the proposed structure works perfectly as a polarizer and can polarize up to $\theta = 60^0$ with significantly less marginal bandwidth compared to the normal EM waves incidences. We can infer that our proposed FSS polarizer works fine with different theta(θ) variations for both $ø = 0^0$ and $ø = 90^0$.

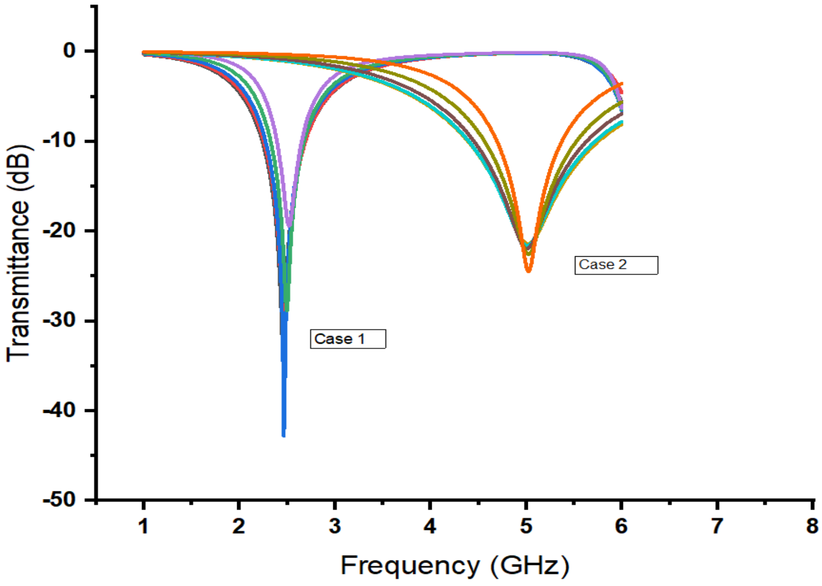

Fig 5(c): Transmission coefficient at oblique incidence ($ø=90^0$)

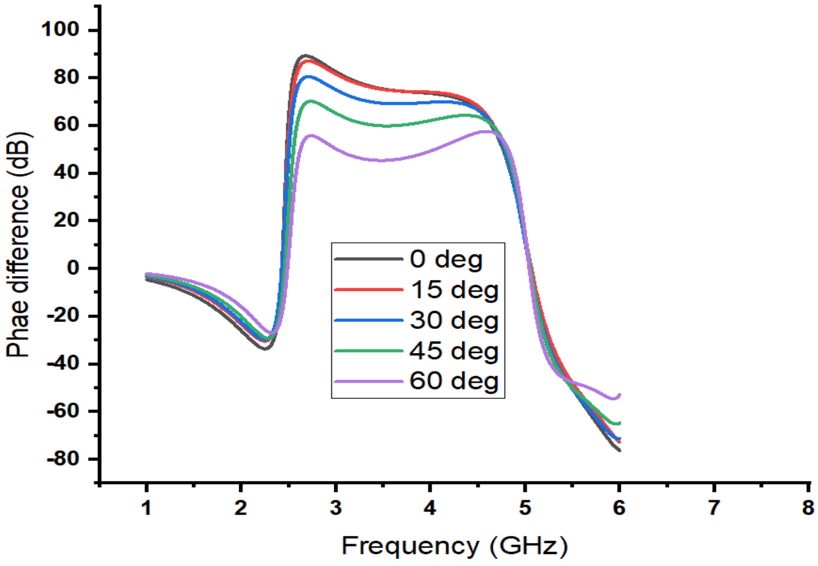

Fig 5(d): Phase difference at oblique incidence ($ø=90^0$)

It is crucial to account for some misalignment of antennas with respect to the axis when installing a polarization-processing device in reality. To test the proposed structure's oblique incidence characteristics theta variation from 0^0 to 60^0 with a step of 15^0 for both $ø=0^0$ and $ø=90^0$ have been established through simulation. The transmittance and phase difference for $ø=0^0$ and $ø=90^0$ is reported. The above results shows that the proposed FSS's polarization filtering capabilities have high stability for the variation of incidence angles taken into account. The phase difference at oblique incidence shows some variation at the considerable range of frequencies.

Field Images:

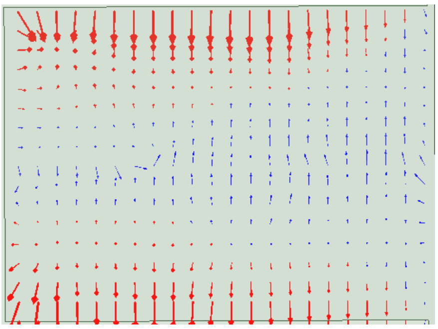

Fig 6(a): E-field image for case 1

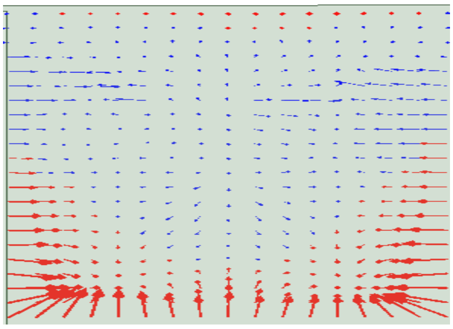

Fig 6(b): E-field image for case 2

The above two figures represent the E-field images of both case 1 and case 2. The results shown that the E-filed intensity is more at the edges.

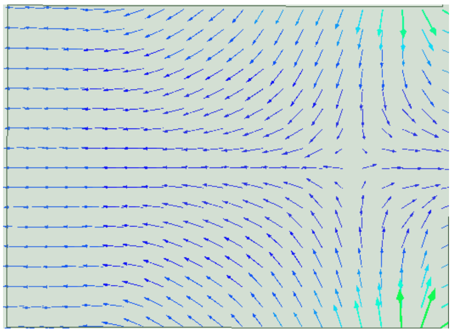

Fig 7(a): H-field image for case 1

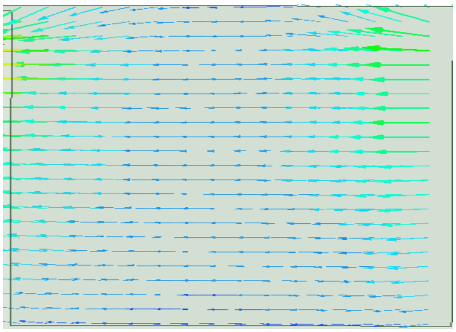

Fig 7(b): H-field image for case 2

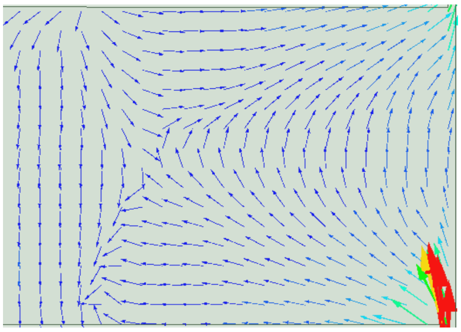

Fig 8(a): Surface current image for case 1

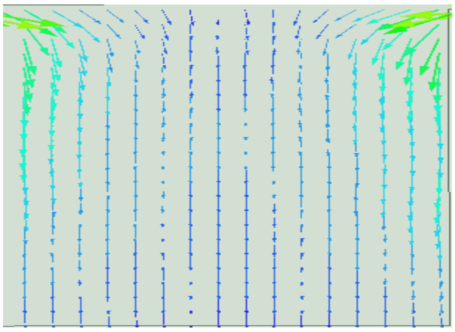

Fig 8(b): Surface current image for case 2

The above images show the H- field and Surface current images for both case 1 and case 2. Both H-field and Surface current distribution is uniform in case 2.

IV. Conclusion

A low profile, microwave FSS polarizer was designed using HFSS software. The proposed microwave polarizer operating at frequencies **f=2.45GHz** and **f=5GHz** works perfectly and can be utilized for specific applications of Microwave oven and 5G Communications. In this paper, we performed parametric studies to understand the stability of our proposed FSS Polarizer. We have investigated the structure's performance at different angles of incidences(θ). These studies were performed to verify our microwave FSS Polarizer. Therefore, the proposed microwave FSS Polarizer succeeds in working at specific applications of Microwave oven and 5G Communications. The simulated design can be utilized practically by use of fabrication and this surface is incorporated between antennas to function as a polarizer. Over the years the demand has increased and they succeeded in bandwidth enhancement and quality of reception between antennas due to their thin profile characteristics. Hence a new class of FSS-based Polarizer is simulated.

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