Novel Broad Band FSS Dual-Layer Circular Polarizer Based on Quarter Wave Plate

Farman Ali Mangi, Shaoqiu Xiao, Saeed Ahmed Khan, Imran Memon, and Deedar Ali Jamro

***Abstract*—In this paper, a novel design of broadband frequency selective surface dual layer circular polarizer based on quarter wave plate is presented to analysis transmission characteristics at operated frequencies for the X-band applications. The efficient techniques are employed to achieve high polarization efficiency, optimal performance and good circular polarization around resonant frequencies. Widening bandwidth through polarizer has been an important issue for researchers; therefore significant technique is employed to improve bandwidth widening of polarizer at transmitted frequencies. Our results show that cross dual layer polarizer transmits left handed circular polarization (LHCP) at 9.60 GHz and right hand circular polarization (RHCP) at 10.65 GHZ with axial ratio across 9.24-10.99=17.12% bandwidth, respectively.**

***Index Terms*—Circular polarization, dual layer polarizer, frequency selective surface (FSS), Fabry-Perot Interferometer, quarter wave plate.**

I. Introduction

In microwave communication system, radar, tracking system and wireless communication system circular polarization has great importance because a circular polarization possesses the lower susceptibility to the reflection effects, atmospheric absorption and multipath. The circular polarization of waves is widely used in Satellite Communications Systems, Global Positioning System (GPS), and Radio Frequency Identification (RFID).

Circular polarizers based on meander line in microwave technology is introduced by Young [1] and presented by Munk [2]. Currently, Euler [3] has introduced the various types of dual layer circular polarizers in which the space between the surfaces of layers is adjusted by the Fabry Perot interferometer approach [4]. Quarter wave plate is another approach to transfer linearly polarized waves to circularly polarized waves. A quarter-wave plate converts electromagnetic waves from linearly to circularly polarized states or vice versa [5], [6]. The high quality circular polarization waves over broad band range can be produced by quarter wave plate. For a quarter wave plate, the transmitted phase difference of two orthogonal components of electric field is a quarter of a wavelength (900). When an incident field is linearly polarized at 450 and the quarter wave plate converts the transmitted field to circular polarization, which has applications in satellite communication and rain clutter suppression [7].

For several years, FSS has gained more attention in modern communication. Frequency selective surfaces (FSSs) are also used as polarizers, polarization transformer, filters, and passband hybrid radomes for radar cross section (RCS) controlling [8]-[13]. They are attributable to contribute overall stable performance for different incidence angles, polarization states and offering the simple fabrication. The previous FSS polarizers were designed on the basis of cross dipole structures and fabricated for high frequency applications.

Previous contributed research on FSS Polarizers was carried out on the cross dipole structure for high frequency applications. The bandwidth widening through the polarizer is an important issue in the field of wireless communication system. M. Euler and *et al.* achieved minimum Axial Ratio 3dB and axial ratio bandwidth of 0.5% with -3.2 transmission loss of polarizer [14]. Masa-Campos and *et al.* used the double-layer polarizer approach to obtain circular polarization in order to 3dB axial ratio on operational bandwidth of 5.7% [15]. G. I. Kiani and *et al.* observed the transmission loss 6 dB with narrow band and 1.0 axial ratio through polarizer at 75 GHz [16]. Ranga *et al.* introduced single layer transmission polarizer with Jerusalem cross FSS design in which bandwidth performance of 3.4% with 3dB axial ratio and transmission loss 3.1 dB was found at 17.8 GHz [17]. Currently, the FSS circular polarizers have narrow bandwidth performance with poor efficiency of transmission; therefore research is needed to improve the bandwidth performance with low loss transmission of polarizer to achieve perfect circular polarization.

Currently, the FSSs circular polarizers have narrow bandwidth performance with poor efficiency of transmission; therefore research is needed to improve the bandwidth performance with low loss transmission of polarizer to achieve good circular polarization.

In this work, a novel technique is used to design FSS dual-layer circular polarizer to improve the bandwidth around operated frequencies. The significant advantage of this proposed design model over at present available FSS circular polarizers, such as, broadband, good circular polarization, simple structure, high polarization efficiency, low loss transmission and possess easy and efficient fabrication techniques. The basic purpose of this study is to

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investigate the transmission characteristics of FSS dual layer polarizers and introduce the efficient techniques to design dual-layer polarizer that are quite different from previous published contributions.

II. Design Process and Simulation Setup

In this work, a simple low profile prototype dual-layer structure is designed in x, y-directions, respectively.

In Fig. 1, schematic structures of two strips are grounded on substrate and oriented at an angle 45° and – 45° along the x-y direction to compose dual layer circular polarizer. Two strips are separated at a distance *r* from each other. The thickness and relative permittivity of the substrate are *t* and ξ_r, respectively. The length and width of each layer structure l and wide *w* as shown in Fig. 1. The periods in x- and y-direction are P_x and P_y, respectively.

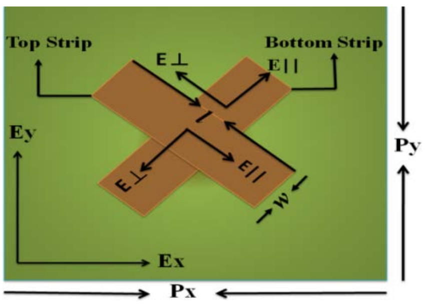

Fig. 1. The dimensions of the dual layer strips with electrical field orientation.

In simulation setup, x-polarized wave as excitation source through floquent port one and unit cell boundary conditions have been applied directly. The schematic of unit cell is constituted on the basis of rectangular metallic strips mounted on the dielectric substrate. Whereas, the perfect electric conductor (PEC) is assigned to the strips, however, low dissipation characteristic of this loss material (Roger RT/duroid 5880 tm). The structure parameters of dual layer polarizer are selected as *l* = 11 mm, *w* = 3.74 mm and $\boldsymbol{P_x}$ = 24 mm and $\boldsymbol{P_y}$ = 24 mm. Meanwhile, the structure parameters of dual layers polarizer are selected as *l* = 11 mm, *w* = 3.74 mm, ***r*** = 2 mm, *t* =0.508 mm and ξ_r =2.2 respectively (see Fig. 2).

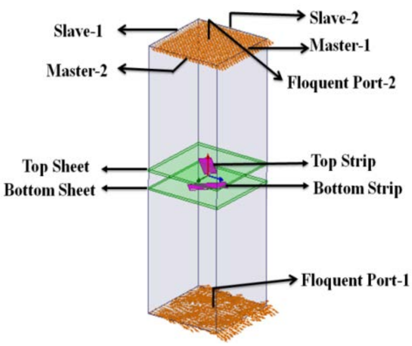

Fig. 2. Simulation model of dual layer polarizer.

III. Result and Discussion

The incident linearly polarized wave Ei from radiating metallic strip is decomposed in to two orthogonal and linear electric field vector components (*E*|| and *E*⊥) with equal magnitude and 90° phase difference. When *EM* wave is passed through polarizer, the circular polarization is generated when the magnitudes of two orthogonal components (*ET*|| and *ET*⊥) are same. The phase difference 900 between them can be expressed as.

$$\Delta\phi = \phi y - \phi x = n\pi, \text{ where } n = 0, 1, 2 \qquad (1)$$

The *E* field decomposed in two orthogonal components of E_x and E_y having equal magnitude.

$$\mathrm{E}(t) = \hat{x}E_X(t) + \hat{y}E_Y(t) = \tilde{E} = \hat{x}\tilde{E}_X + \hat{y}\tilde{E}_Y \qquad (2)$$

$$E_x(t) = mx\cos(\omega t - Kz)$$

$$E_y(t) = my\cos(\omega t - Kz + \delta)$$

where *x* and *y* subscripts represents the polarization states of transmitted/incident waves components, *k* is the wavenumber, *ω* is the frequency, *t* is time, and *δ* is the phase offset between the two waves.

According to the strips orientation, thickness of substrate and its constitutive relation, RHCP and LHCP are obtained when two linearly polarized components possess equal magnitude with respect to 90° phase shift at operated frequencies.

The x-polarized wave incident on bottom layer through floquent port one +Z-direction produce resonance on the layer. The degeneracy of two polarized waves is divided in to refractive indices of RHCP wave and LHCP wave according to media constitutive relation. The mechanism of resonance can be easily understand by determining the surface current distributions on bottom layer for LHCP wave at 9.60 GHz and top layer for RHCP wave at 10.65 GHz, respectively as shown in Fig. 3.

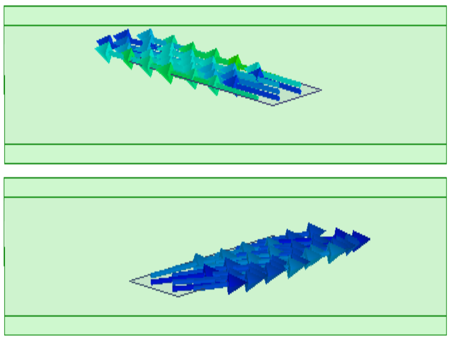

Fig. 3. The surface current distribution of top and bottom layers structure at 9.60 GHz for LHCP wave and 10.65 GHz for RHCP wave. The linear arrows represent the surface current distribution and direction of polarized waves.

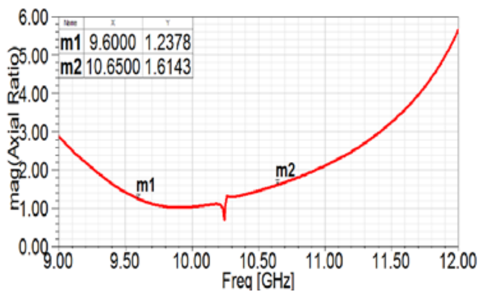

Fig. 4. Axial ratio versus frequency of single Polarizer.

Obviously, two transmitted frequencies (9.60 GHz and 10.65 GHZ) for the RHCP and LHCP waves caused by dual layer polarizer. As shown in Fig. 3, the surface current distribution on the top and bottom layer of dual Polarizer for LHCP wave at 9.60 GHz and RHCP wave at 10.65 GHz is noticed between 9.24 GHz -10.99 GHz bandwidth.

The clockwise rotation is determined by rotating phase leading x-component towards the phase lagging y-component. Meanwhile, the anticlockwise rotation caused due to, the phase leading y-component towards the phase lagging x-component. The phase difference and equal magnitudes of two orthogonal components can be expressed for RHCP and LHCP are respectively as follow.

$$\Delta\emptyset = \emptyset\mathbf{y} - \emptyset\mathbf{x} = \begin{cases} +\left(2n+\frac{1}{2}\right)\pi, & \text{for RHCP} \\ -\left(2n+\frac{1}{2}\right)\pi, & \text{for LHCP} \end{cases} \qquad (3)$$

The following expressions show the equivalent magnitudes of RHCP and LHCP at transmitted resonant frequencies.

$$E_0(z,t) = \frac{E_0}{\sqrt{2}}\cos(Kz-\omega t)\hat{x} + \frac{E_0}{\sqrt{2}}\sin(Kz-\omega t)\hat{y} \qquad (4)$$

$$E_0(z,t) = \frac{E_0}{\sqrt{2}}\cos(Kz-\omega t)\hat{x} - \frac{E_0}{\sqrt{2}}\sin(Kz-\omega t)\hat{y} \qquad (5)$$

The ratio of two magnitudes of transmitted field components is given by following expression.

$$\mathrm{q} = |E_x|/|E_y| \quad \text{In other word}$$

$$|E_x|\,.\,T^x = |E_y|\,.\,T^y \qquad (6)$$

Here, axial ratio q = ⊂ [1] and T^X and T^Y are transmitted amplitude of EX and EY which explains the minor to major axis ratio of the polarization when q = 1, It obtains circular polarization provided that

$$[ang\,(E_y) + ang\,(T^y)] - [ang\,(E_x) + ang\,(T^x)] = \pm\frac{n\pi}{2} \qquad (7)$$

where *n* = 1, 2, 3,

The transmission of *E* field E_x and E_y components possess equal phase and magnitude which is required for the circular polarization

$$|T^x| = |T^y| \qquad (8)$$

$$[ang\,(T^y)] - [ang\,(T^x)] = \pm\frac{n\pi}{2} \qquad (9)$$

The distance between strips, length and width of the strips minimize the reflection effect of first and second layer of the polarizer and two vector components of the *E* field *ET*|| and *ET*⊥ having equal magnitude and 90° phase difference between to them to produce circular polarization. The axial ratio of transmitted wave is used to specify the quality of circular polarization produced by the polarizer. Generally, the axial ratio is acceptable between 0 and 3 dB for circularly polarized wave.

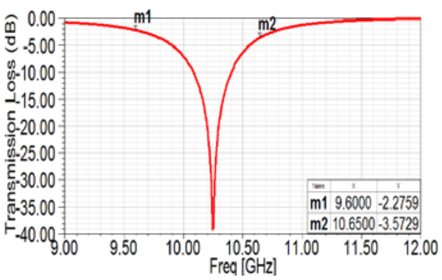

Fig. 5. Transmission loss of E-field versus frequency of dual layer polarizer.

The simulated axial ratio versus frequency response is obtained to be1.5 at 9.3 GHz and 1.6 at 10.73 GHz as shown in Fig. 6. The axial ratio bandwidth of operated frequencies is extended (9.24-10.97 GHz = 17.12% bandwidth) as shown in Fig. 4.

The transmission loss of dual layer polarizer versus frequency -2.2 dB at 9.6 GHz and -3.5 at 10.6 GHz is observed as shown in Fig. 5.

The phase shift of two orthogonal components E_x and E_y is achieved -89.17 at the 9.6 GHz and 900.9 at 10.65 GHz as shown in Fig. 6.

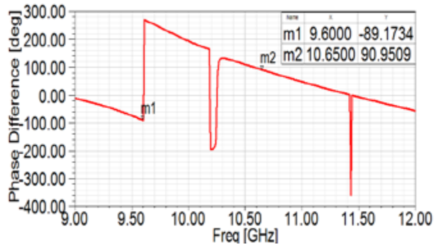

Fig. 6. Phase difference of E-field versus frequency of single polarizer.

The bandwidth axial ratio of dual layer polarizer is obtained (9.24 GHZ-10.97 GHZ = 17.12 % bandwidth) and 3.1 dB axial ratio is found between 9.24 and 10.97 GHz as shown in Fig. 7.

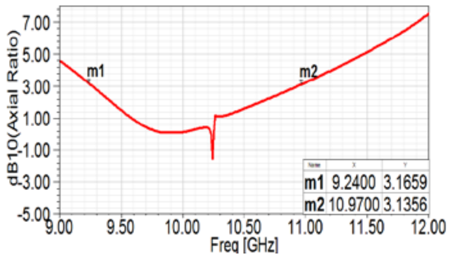

Fig. 7. The axial ratio bandwidth versus frequency of single layer polarizer.

The transmission characteristics of dual layer polarizer has been analyzed significantly. The key features of proposed polarizers to generate RHCP and LHCP to achieve optimal bandwidth at resonant frequencies. In Fig. 7, the axial ratio bandwidth (9.24-10.97=17.12%) of dual layer polarizer is noticed at resonant frequencies across 9.60 GHz and 10.65 GHz. The simulation results show the transmission resonant frequency 9.60 GHZ, for LHCP wave and 10.65 GHz for RHCP wave, respectively.

The significant feature of designed dual layer polarizer is that it covers X-band applications and possesses the significant advantage of large bandwidth as compare to previous published research contribution. Depending on the strips parameter, orientations and thickness of dielectric plates, RHCP and LHCP wave can be occurred. The large bandwidth achieving over the operating bands depend on the key parameters in design of dual layer polarizer; for instance, the length of strips, small thickness of substrate, orientations of layers and specific boundaries conditions, respectively.

IV. Conclusion

The object of this research is to observe the transmission characteristics of dual layer polarizers. The performance of dual layer polarizer is computed with HFSS simulation. The designed model of polarizer is very simple and can be easily fabricated. Therefore, the same technique can be applied to design circular polarizers for millimetre, micrometre and terahertz frequencies according to the desired applications. In the future, the research can be carried out to design and optimize such polarizers based on frequency selective surface to enhance the bandwidth and minimize the transmission loss. The results of our research exhibits good correspondence with simulation and optimization. Nevertheless, it could be possible to improve the bandwidth performance and minimize the transmission loss of circular polarizer by changing some parameters, such as by extending the multilayer, increasing or decreasing the length of each strips, thickness of substrate and strips and adjusting the distance between layers, respectively.

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