Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48 (1) 125-130 (2016)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

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

F. A. MANGI, G. A. MALLAH*, A. A. SHAH**

School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu, 610054 Sichuan, China

Received 21st September 2014 and Revised 22nd January 2016

Abstract: A broadband FSS dual-layer circular polarizer based on quarter wave plate is proposed which is composed of two ultrathin periodic metallic strips and comprehensively investigated that can convert the linear polarized wave into circularly polarized wave under the normal incidence of x-linearly polarized wave over dual bands. The two transmitted linear vector components possess the equal amplitudes and $\pm 90^0$ phase difference around the frequency bands. This means the transmitted waves are achieved with right handed circular polarization and left handed circular polarization at resonance frequencies. The two ultrathin periodic metallic strips are printed on the top and bottom surfaces of two dielectric substrates along x, y direction which are subjected to broaden the axial ratio bandwidth at frequency bands. Moreover, the accumulated axial ratio bandwidth of single and dual-layer polarizer is achieved of 5.14% and 14.11% over the frequency bands for circular polarization.

Keywords: Circular polarization, dual layer polarizer frequency selective surface (FSS), quarter wave plate,

1. INTRODUCTION

into three states, linear polarization, circular polarization and elliptic polarization which are used in engineering. In general, the linearly polarization state can be manipulated into circular polarization under the incidence of plane wave. A circular polarizer (Chu, *et al.,* 1987).can be used to convert linearly polarized wave into circular polarized wave under the incidence of plane wave and has been widely used in the remote sensing, satellite communications systems and optical communications (De, *et al.,* 1996) (Euler, *et al.,* 2010). (Euler, and Fusco, 2008), (Gansel, *et al.,* 2009). (Huang, *et al.,* 2014). Huang, *et al.,* 2007). (Marc-Andre., *et al.*, 2011). (Kaschke, *et al.*, 2012) (Lier *et al.*, 1988) waveguide (Masa-Campos, *et al.*, 2009). (Mutlu, *et al.*, 2011)In addition, they are used as filter which contribute overall stable performance to pass incident to circularly polarized wave under the different incidence angles.

According to existing research contribution, circular polarizers are proposed by employing chiral met material, meta surface Huang, *et al.,* 2007). (Marc-Andre., *et al.*, 2011). (Kaschke, *et al.*, 2012) (Lier *et al.*, 1988) waveguide (Masa-Campos, *et al.*, 2009). (Mutlu, *et al.*, 2011) meander line slots of various shapes wave have many advantages, for instance, angular tolerance, high conversion efficiency and sub wave length thickness. Unfortunately, they have a common disadvantage of narrow operating bandwidth. Though, wave guide circular polarizer exhibits a wide operating bandwidth with AR less than 3 dB. But they are not suitable for the miniaturized devices applications due to their large thickness. Therefore, researchers suggested to avoid heavy waveguide walls and employing two dimensional grating that can realize the circular polarizers (Munk, 2000)., (Sohail, *et al.*, 2013). (Kiani, *et al.*, 2010)In general, it is observed that if the high permittivity dielectric is employed though it may achieve narrow bandwidth over the frequency bands.

Frequency selective surfaces are also used to control the polarization states of electromagnetic waves. FSS's are employed to manipulate the polarization state from linear-to- circular polarization. They are used as filter and polarization transformer for radar cross section (RCS) controlling RCS) controlling (Wang, *et al.,*2004). (Wang, *et al.,* 2009). (Wu, 1995) (Xu, *et al.,* 2013). They are introduced for polarizer applications and have good advantages of low profile, more favourable among periodic structures and ease fabrication.

In this paper, a broadband FSS linear-to-circular polarizer is proposed with two ultrathin periodic strips. The presented design realizes to manipulate the polarization state of an incident of x-linearly polarized plane wave. Initially, the ingenious introduction of single strip printed on the top of the dielectric substrate to convert linearly polarized wave into circularly polarized waves under the normal incidence of x-polarized wave. The proposed single layer polarizer performs as transmission polarizer over frequency bands that convert an incoming linearly polarized wave into outgoing circularly polarized wave.

++Corresponding author 'Farman Ali Mangi, farmanali29@yahoo.com, Cell # +8615002836807
* Shah Abdul Latif University, Khairpur, Sindh, Pakistan
**University of Sindh, Jamshoro

The accumulated axial ratio bandwidth of single layer polarizer is achieved of 5.14% over a wide frequency range from 9.16 GHz to 9.45 GHz and 10.6 GHz to 10.85 GHz. In order to achieve linear-to-circular polarization by single layer circular polarizer, the transmitted RHCP waves are achieved from 9.16 GHz to 9.45 GHz and LHCP waves are achieved 10.6 GHz to 10.85 GHz, respectively. In this research, the significant technique of dual strips printed on the top and bottom of two substrate separated by small distance is introduced to enhance the band width of circular polarizer.

The double layer circular polarizer helps to significantly broaden the axial ratio bandwidth and achieve good circular polarization over the frequency bands. The linear-to-circular polarization conversion transmission of dual layer circular polarizer is greater than single layer circular polarizer. Moreover, the accumulated axial ratio performance of dual layer circular polarizer for the transmitted wave is achieved of 14.11% over wide range from 9.28 GHz to 9.98 GHz and 9.99 GHz to 10.37 GHz and the transmitted RHCP waves are achieved from 9.28 GHz to 9.98 GHz and LHCP wave are achieved 9.99 GHz to 10.37 GHz, respectively.

The subject of this structure employs to manipulate the polarization state of an incident plane wave of x-linear polarization into circularly polarized wave. The presented structure is constructed by dual layer of substrates, where, two periodic metallic strips are printed on the top and bottom surfaces of induvial substrate sheets. The proposed designed structure has good advantage over the some existing designed polarizers, for instance, good circular polarization, bandwidth widening, easy fabrication, and simple structure. The purpose of this study to investigate the reflection and transmission characteristics, achieving good circular polarization and enhance the axial ratio bandwidth the polarizer. We have presented simple and an efficient designing techniques of proposed structure that are quite different from previous designed polarizers.

2. DESIGNED MODEL

(Fig. 1 and 2) depicts the unit cell of single ultrathin layer circular polarizer and dual layer circular polarizer. Single layer polarizer shows the single metallic strip printed on the top of the dielectric Roger tilted at 45^0 along *x y* plane. Meanwhile, two ultrathin periodic strips are employed to design dual layer circular polarizer as shown in Fig.2. Whereas, two metallic strips are printed on the top of the substrate-1 (dielectric Roger) and other strip is printed on the bottom of the substrate-2 (dielectric Roger) slanted at 45^0 and 90^0 along *x y* plane. The distance between two substrate is represented by *r*. The period constant of single layer polarizer is represented by p. The width and length of structure are represented by *w* and *l*. The permittivity and thickness of the substrate are represented by and ξ, and h respectively.

In simulation setup, a broadband x-linearly polarized wave incident along +z direction and assign directly boundary conditions for unit cell. The printed periodic strips on the substrate are assigned by perfect electric conductor (PEC). The structure parameters of single and dual layer polarizers are presented as follows; the model periodic boundaries condition are along x and y directions are shown as px =25 mm, py = 25 mm, respectively. The dielectric substrate printed with metallic strips with length and width *l* = 11mm, *w* = 3.74 mm. The dielectric substrate Roger RT/duroid5880 is chosen with relative permittivity $\mathcal{E}r$ = 2.2 and loss tangent of 0.0009. The substrate thickness t = 0.508 mm. The distance between two substrate of dual layer polarizer is *r* = 2 mm, respectively.

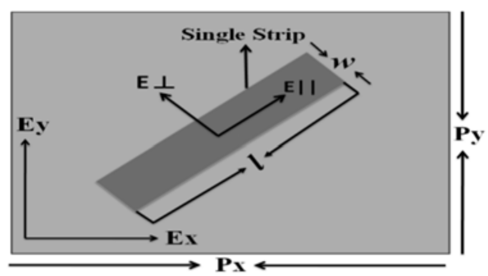

Fig. 1.The dimensions of single layer strip with electrical field orientation

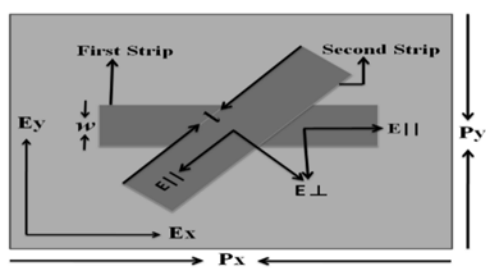

Fig. 2.The dimensions of the dual layer strip with electrical field orientation

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 cells are 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 lossy material (Roger RT/duroid 5880 tm) is favourable for Ku band. The structure parameters of single layer polarizer are selected as ***l*** =11.2mm, ***w***= 3.74mm and **p*x***=25 mm and **p*y***=25 mm. Meanwhile, the structure parameters of dual layers polarizer are selected as l = 11mm, w = 3.74mm, r =2 mm and px = 22.6 mm and py = 22.6 mm, h =0.508 mm and$\mathcal{E}r$ =2.2and loss tangent of 0.0009, respectively.

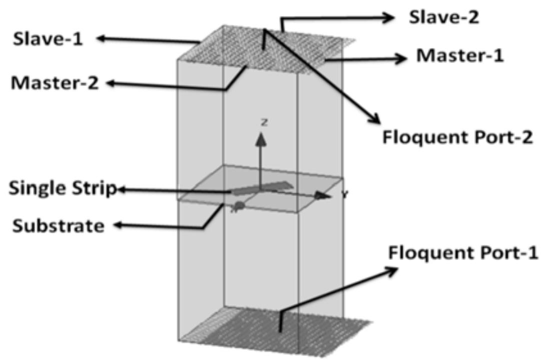

Fig. 3. Simulation model of Single layer polarizer

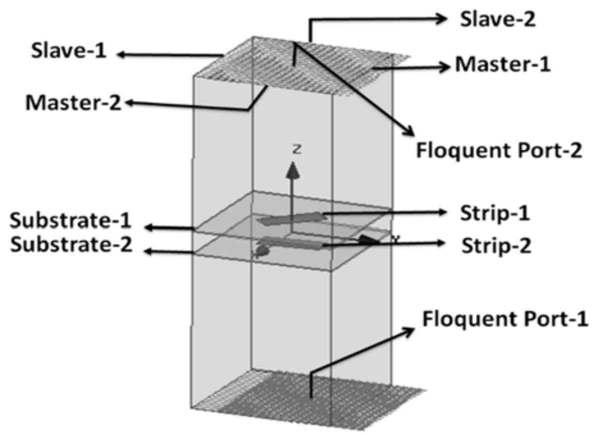

Fig. 4. Simulation model of dual layer polarizer

3. RESULTS AND DISCUSSION

The principle of operation to convert linear to circular polarization of proposed circular polarizer, a linearly polarized incident plane wave with polarization angle φ = 45^0 can be decomposed into two orthogonal vector components (**E**$_{\|}$ and **E**⊥) after the transmission through polarizer. The incident linearly polarized wave decomposed in two orthogonal vector components of Ex and Ey having equal magnitudes from other side of polarizer.

Considering an incident plane propagating along negative z direction, with electric field

$$E_I\,(r,t) = \begin{pmatrix} i_x \\ i_y \end{pmatrix}\; e^{i\,(kz-wt)} \qquad (1)$$

Where, ω represented as frequency, k being wave vector *ix* and *iy* are the complex amplitudes, respectively, which explain the state of linear polarization.

$$E_t\,(r,t) = \begin{pmatrix} t_x \\ t_y \end{pmatrix}\; e^{i\,(kz-wt)} \qquad (2)$$

The incident plane wave and transmitted wave can be expressed as

$$\begin{pmatrix} t_x \\ t_y \end{pmatrix} = \begin{pmatrix} T_{xx} & T_{xy} \\ T_{yx} & T_{yy} \end{pmatrix} \begin{pmatrix} i_x \\ i_y \end{pmatrix} \qquad (3)$$

For the better understanding the cross-polarization conversion based on proposed structure, the invoked transmission matrix (T matrix) expression which correspond to the incident and transmission field.

$$\begin{pmatrix} E_x^t \\ E_y^t \end{pmatrix} = T \begin{pmatrix} E_x^i \\ E_y^i \end{pmatrix} = \begin{pmatrix} T_{xx} & T_{xy} \\ T_{yx} & T_{yy} \end{pmatrix} \begin{pmatrix} E_x^i \\ E_y^i \end{pmatrix} = \qquad (4)$$

On the basis of circular polarization, the "T" matrix is associated to the incident and transmitted circularly polarized wave which propagates in forward direction and generated from linear transmission coefficients.

$$\begin{pmatrix} E_+^t \\ E_-^t \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} E_x^t + jE_y^t \\ E_x^t - jE_y^t \end{pmatrix} = T \begin{pmatrix} E_x^i \\ E_y^i \end{pmatrix} \qquad (5)$$

$$\begin{pmatrix} T_{+x} & T_{+y} \\ T_{-x} & T_{-y} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} T_{xx} + iT_{yx} & T_{xy} + iT_{yy} \\ T_{xx} - iT_{yx} & T_{xy} - iT_{yy} \end{pmatrix} \qquad (6)$$

Where, the subscript "+" and "-"represent for the RHCP wave and LHCP wave, respectively. While, the power normalization is represented by the constant $\frac{1}{\sqrt{2}}$. The array of the elements in matrix involve the ability of proposed structure to transmit circular polarization wave (Wu, 1995)

Obviously, two transmitted frequencies (9.34 GHz and 10.73 GHZ) for the RHCP and LHCP waves caused by single layer polarizer as shown in Fig.5.(a). According to **(Fig. 5 (b),** one transmitted frequency 9.59 GHz is attributed to dual layer polarizer for RHCP waves. The resonance mechanism of proposed layer structures can understand by explaining the surface current distributions on the top and bottom layer of dual polarizer for RHCP. The parallel currents flowing on the single and dual strips which indicated the modes of symmetric current resonance at the transmitted frequencies as shown in **(Fig 5. (a and b).**

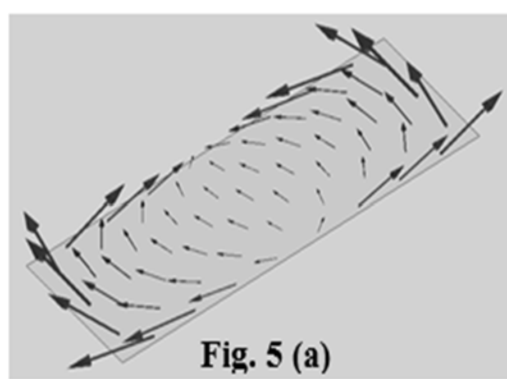

Fig.5: (a)The surface current distribution of single layer structure at 9.34 GHz and 10.73 GHz for RHCP and LHCP, respectively.

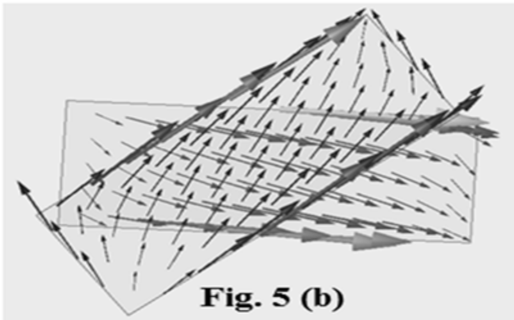

Fig.5. (b) The surface current distribution of top and bottom layer of proposed dual layer structure for RHCP wave sat 9.59 GHz. The linear arrows represent the surface current distribution and direction of polarized waves.

Fig.5. (b) The surface current distribution of top and bottom layer of proposed dual layer structure for RHCP waves at 9.59 GHz. The linear arrows represent the surface current distribution and direction of polarized waves.

(Fig.6) represents the reflection of single layer polarizer under the normal incidence of electric field. The reflection coefficients are -8.70 dB (f1 = 9.34GHz), and -13.62 dB (f2 = 10.73 GHz), respectively. Meanwhile, the transmission coefficients of Txx and Txy are -2.19 dB, -1.4 dB and -5.82 dB -6.07 dB at 9.34 GHz, 10.73 GHz, respectively, as shown in **(Fig. 7).**

The axial ratio is calculated as shown in Fig. 8 and the corresponding phase differences results are presented in Fig. 9 which associated to the values of phase difference at the operated frequency bands, where, the values of axial ratio are 1.5(f1 = 9.34GHz) and 1.6 (f2 = 10.73 GHz), respectively. The corresponding phase differences are calculated to be 9.90^0(f1) and -90.44^0(f2), respectively.

(Fig. 8,9) represents the large axial ratio bandwidths at two resonances ranging from 9GHz-12GHz, which are contained at 9.16–9.45GHz, BW = 2.76% and 10.6–10.85 GHz, BW= 2.38%. It can be observed that the accumulated axial ratio bandwidth of 5.14% is obtained at the two corresponding frequency bands ranging from 9GHz-12GHz.

The RHCP wave are obtained at bandwidth = 9.16–9.45 GHz and LHCP wave are achieved at bandwidth = 10.6–10.85 GHz, respectively.

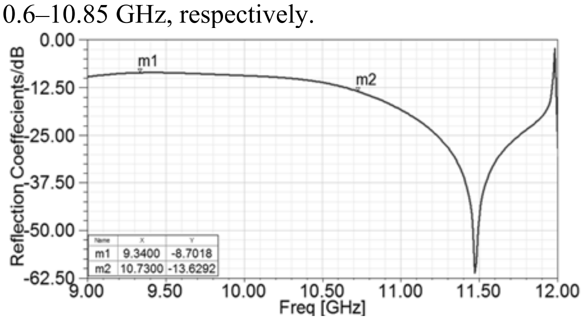

Fig. 6. Reflection coefficients versus frequency of single-layer circular polarizer

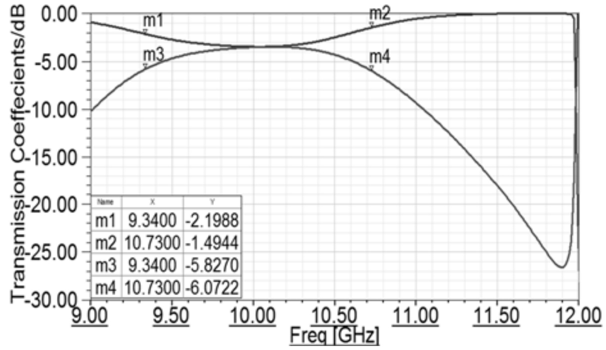

Fig.7. Transmission coefficients of Txx and Txy versus frequency of single -layer polarizer.

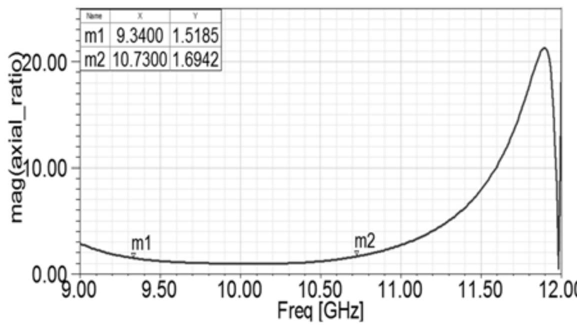

Fig. 8. Simulated axial ratio versus frequency of single-layer circular polarizer

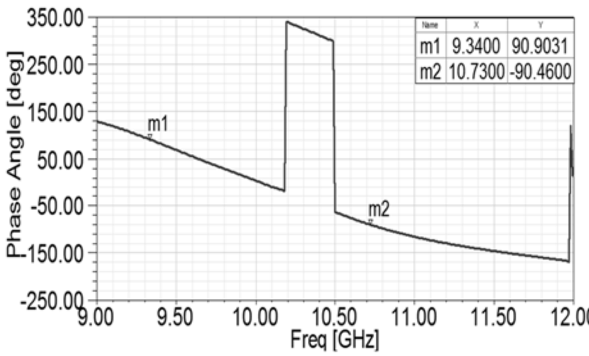

Fig.9. Phase difference between transmitted waves versus frequency of single-layer circular polarizer

The reflection coefficients of double-layer circular polarizer under the normal incidence of electric field is represented by **(Fig 10).** The reflection coefficients are –9.22 dB (f1 = 9.58GHz), and -2.35 dB (f2 = 10.20 GHz), respectively. Meanwhile, the transmission coefficients of Txx and Txy are obtained -2.27 dB (f1), -7.97 dB (f2) and -5.43 dB (f1), -5.93 dB (f2), respectively as shown in **(Fig. 11).** The axial ratio between transmitted wave is calculated as shown in **(**Fig. **12)** and the corresponding phase differences results are presented in **(Fig. 13)** which associated to the values of phase difference at the operated frequency bands, where, the values of axial ratios are 1.4 (f1 = 9.58GHz) and 0.79 (f2 = 10.20 GHz), respectively. The corresponding phase differences are calculated to be 9.3^0(f1) and -270.0^0(f2), respectively.

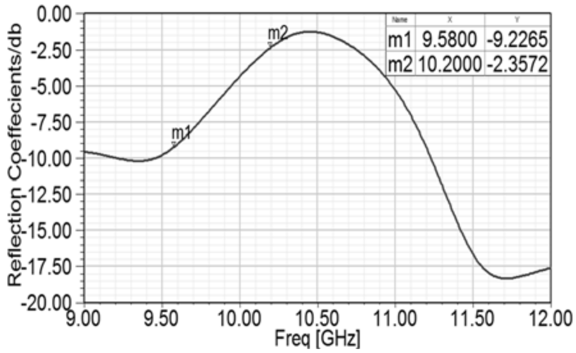

Fig. 10. Reflection coefficients versus frequency of dual-layer circular polarizer

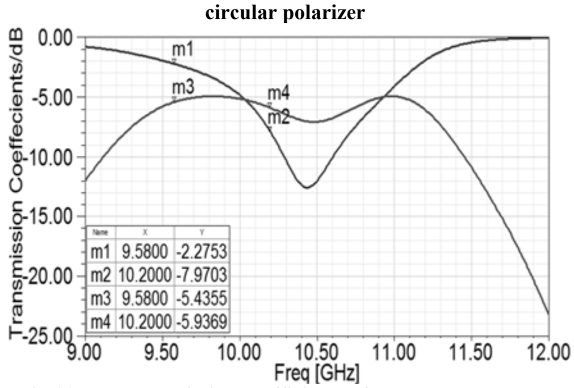

Fig.11. Transmission coefficients of Txx and Txy versus frequency of dual -layer circular polarizer.

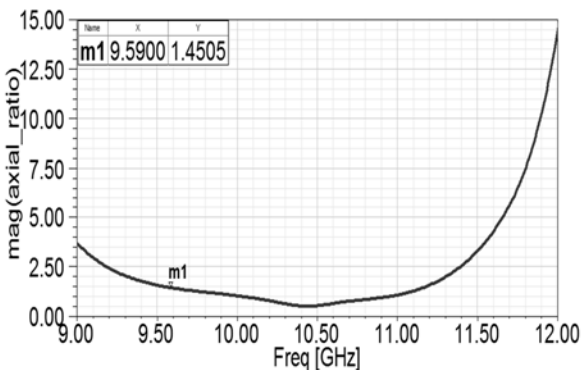

Fig. 12. Simulated axial ratio versus frequency of dual-layer circular polarizer

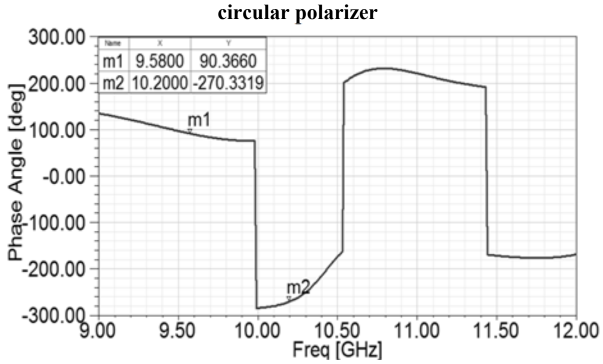

Fig.13. Phase difference of E-field versus frequency of dual-layer circular polarizer

The transmission and reflection characteristics and co-cross polarization of designed single-layer structure and dual-layer structure has been evaluated significantly. The significant advantages of proposed structures is to achieve broadband axial ratio bandwidth and the RHCP and LHCP wave at resonant frequencies. It can observed that the axial ratio bandwidth of single-layer polarizer and dual-layer polarized is achieved by using significant technique to convert linear-to-circular polarization. The reflection coefficients of single- and dual-layer polarizer are less than -9 dB better than reported research contribution. It means that the good linear-to-circular polarization conversion is obtained and axial ratio for the transmitted wave is near to 1.0 in the frequency range of 9GHz-12GHz. The accumulated axial ratio of single and dual layer polarizer has been achieved 5.14% and 14.11% at operated frequency bands.

4. <u>CONCLUSION</u>

A broadband FSS dual-layer circular polarizer based on quarter wave plate is proposed which converts the linearly polarized incident wave into circularly polarized wave. The dual-layer circular polarizer is composed of printed periodic metallic strips which is subjected to enhance the axial ratio bandwidth around the resonance frequencies. The transmission and reflection characteristics of individual polarizers has been analyzed. The performance of both circular polarizers is computed with HFSS simulation. The designed models of polarizers are very simple and can be easily fabricated. Moreover, the research can be carried out to introduce polarizers based on frequency selective surface using multilayers to enhance the bandwidth and minimize the transmission loss. Obviously, it can be improved the bandwidth performance of circular polarizer by printing the multilayer, increasing or decreasing the length of strips, thickness of substrate and adjusting the distance between layers, respectively. Our proposed circular polarizer have good performance for x-band applications and can be employed in instrumentations and optical communications.

<u>REFERENCES:</u>

Chu, R. S., and K. M. Lee, (1987).“Analytical model of a multilayered meander-line polarizer plate with normal and oblique plane-wave incidence,” IEEE Trans. Antenn. Propag. 35(6), 652–661.

De, A. C., C. Lima, and E. A. Parker, (1996).“Fabry–Perot approach to the design of double layer FSS”, IEE Proceedings on Microwaves, Antennas and Propagation, 143, 2, 157–162.

Euler, M., and V. Fusco, (2008). "Sub-millmeter wave linear to circular polarizer converter", Antennas and Propa. conf., 77-80.

Euler, M., V. Fusco, R. Dickie, and R. Cahill, (2010). "Comparison of frequency-selective screen-based linear to circular split-ring polarization convertors," IET Microwave Antennas Propag. 4(11), 1764–1772.

Gansel, J. K., M. Thiel, M. S. Rill, M. Decker, K. Bade, V. Saile, G. von Freymann, S. Linden, and M. Wegener, (2009). "Gold helix photonic met material as broadband circular polarizer," Sci. 325(5947), 1513–1515.

Huang, X. J., and H. L. Yang, (2014). "Multiple-band reflective polarization converter using U-shaped met material," J. Appl. Phys. 115(10), 103-505.

Huang, Y., Y. Zhou, and S. T. Wu, (2007). "Broadband circular polarizer using stacked chiral polymer films," Opt. Express 15(10), 6414–6419.

Joyal, Marc-Andre., and Jean-Jacques Laurin, (2011). "A Cascaded Circular-Polarization-Selective Surface at K band" Antennas and Propagation (APSURSI), 2657–2660.

Kaschke, J., J. K. Gansel, and M. Wegener, (2012). "On met material circular polarizer's based on metal N-helices," Opt. Express 20(23), 26012–26020.

Kiani, G. I., and V. Dyadyuk, (2010). "Qurter-wave polariser based on frequency selective surfaces", Micow. conf. (EuMC), 1361-1364.

Li, Y. F., J. Q. Zhang, S. B. Qu, J. F. Wang, H. Y. Chen, Z. Xu, and A. X. Zhang, (2014). "Wideband selective polarization conversion mediated by three-dimensional met materials," J. Appl. Phys. 115(23), 234-506.

Lier E., and T. S. Pettersen, (1988)."A novel type of waveguide polarizer with large cross-polar bandwidth," IEEE Trans. Microw. Theory Tech. 36(11), 1531–1534.

Masa-Campos, J. L., and F. Gonz´alez-Fern´ (2009). "Dual Linear/Circular Polarized Plannar Antenna With Low Profile Double-Layer Polarizer Of 45◦ Tilted Metallic Strips ForWimax Applications", Progress In Electromagnetics Research, PIER 98, 221–231.

Mutlu, M., A. E. Akosman, A. E. Serebryannikov, and E. Ozbay, (2011)."Asymmetric chiral met material circular polarizer based on four U-shaped split ring resonators," Opt. Lett. 36(9), 1653–1655.

Mutlu, M., A. E. Akosman, and E. Ozbay, (2012). "Broadband circular polarizer based on high-contrast gratings," Opt. Lett. 37(11), 2094–2096.

Mutlu, M., A. E. Akosman, G. Kurt, M. Gokkavas, and E. Ozbay, (2012). "Experimental realization of a high-contrast grating based broadband quarter-wave plate," Opt. Express 20(25), 27966–27973.

Munk, B. A., (2000). Frequency Selective Surfaces: Theory and Design.New York: Wiley.

Sohail, I., Y. G. Ranga, K. P. Esselle, (2013). "A Linear to Circular Polarization Converter Based on Jerusalem-Cross Frequency Selective Surface" Antennas and Propagation (EuCAP), 2141-2143.

Wang, S. W., C. H. Chien, C. L. Wang, and R. B. Wu, (2004). "A circular polarizer designed with a dielectric septum loading," IEEE Trans. Microw. Theory Tech. 52(7), 1719–1723.

Wang, J., and Z. Shen, (2014). "Improved polarization converter using symmetrical semi-ring slots," IEEE Antennas Propag. Society Int. Symp. 2052–2053.

Winkler, S. A., W. Hong, M. Bozzi, and K. Wu, (2009). "A novel polarization rotating frequency selective surface based on substrate integrated waveguide technology," In Proceedings of the 39th European Microwave Conference, Rome, Italy.

Wu, T. K., (1995).Frequency Selective Surface and Grid Array. New York: Wiley.

Xu, H. X., G. M. Wang, M. Q. Qi, T. Cai, and T. J. Cui, (2013). "Compact dual-band circular polarizer using twisted Hilbert-shaped chiral met material," Opt. Express 21(21), 24912–24921.

Yan S., and G. A. E. Vandenbosch, (2013)."Compact circular polarizer based on chiral twist double split-ring resonator," Appl. Phys. Lett. 102(10), 103-105.

Zhu, H. L., S. W. Cheung, K. L. Chung, and T. I. Yuk, (2013)."Linear-to-circular polarization conversion using met surface," IEEE Trans. Antenn. Propag. 61(9), 4615–4623.