Quarter-Wave Plate Polariser Based on Frequency Selective Surface

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***Abstract*— A quarter-wave plate polariser based on frequency selective surface is presented for 75 GHz applications. The FSS consists of a cross dipole on a low loss substrate having different arm lengths in x- and y- directions. This is done to achieve a quarter-wave plate effect at the desired frequency. Theoretically, about 98% circular polarisation is achieved at the centre frequency. Preliminary theoretical results are presented.**

I. INTRODUCTION

Circular polarization (CP) plays an important role in microwave communication systems, radar and tracking applications. Advantages and disadvantages of CP over a linear polarisation have been widely studied and discussed. For example, a circular polarisation has a lower susceptibility to the multi-path, atmospheric absorption and reflections effects. On the other hand, CP has intrinsically lower cross-polarisation discrimination and higher susceptibility to depolarisation by precipitation and ionospheric effects other that Faraday's. Linear polarisation can not be used for applications where polarisation tilt is unknown or is changing dynamically. d a CP is required in these cases, at least, at one of the link nodes.

For the wireless communication between mobile nodes (e.g. inter-aircraft communications), an electronically steerable circular-polarised antenna array is most suitable. The use of active antenna arrays for long-range millimeter-wave ad-hoc communication networks is particularly critical due to increased free space loss and reduced level of practically-achievable output power [1]. Most of known circular–polarised antenna elements consist of several radiation elements and multi-port feed networks. This makes them unsuitable for practical implementation of the millimeter-wave active antenna arrays due to the difficulties in integration of such elements with the RF front end. To date, compact high-performance end-fire antenna array elements [2, 3] that allow seamless integration with the RF front end have been linearly polarised.

One prospective approach to practical realisation of an active circularly-polarised antenna array is the use of a linearly polarised antenna array and electromagnetically coupled polarising wave plate. Dielectric polarisers [6], meander-line [7-9] and grid-plate [10] polarisers have been proposed to convert linear polarised electromagnetic waves to circular.

The property of a non-isotropic transparent material in which the refractive index depends on the polarisation direction (direction of the electric field) is called birefringence. This birefringent property of material makes it capable of exhibiting double refraction to an incident electromagnetic wave. A device or a component that resolves an electromagnetic wave into two orthogonal linear polarised components and produces a phase shift between them is called a wave plate. The intensity of the incident electromagnetic wave does not change after propagating through a wave plate (only the polarisation state is changed). Wave plates are mostly considered as linearly birefringent, which means that the index of refraction differs along the two principal axes, which affects the phase shift of the orthogonal components differently. A quarter-wave plate converts electromagnetic waves from linearly and circularly polarised states or vice versa. The circular polarisation is achieved by phase shifting one component of the linear electric field by $\lambda/4$ (90º) with respect to the other orthogonal component. This is achieved by aligning linearly polarised wave midway (at 45º) between the two axes of a quarter-wave plate [11].

Frequency selective surfaces have been used for many applications such as wireless security, antenna radomes, waveguides, dichroic reflectors and telecommunication [12-17]. FSSs can also act as a quarter-wave plate, offering an ease of fabrication and overall performance [18], however, there use has been very limited [19]. In [20], an FSS polarisation twister is presented which is based on substrate integrated waveguide technology. This FSS can only twist the polarisation by 90º in contrast to a quarter-wave plate polariser which produces a continuously rotating clock or anti-clockwise circular polarisation.

In this paper, a single layer quarter-wave plate polariser based on FSS is presented for 75 GHz applications. The FSS structure is very simple and can easily be fabricated. Using this FSS, about 98% circular polarisation can be achieved at centre frequency.

II. DESIGN OF FSS POLARISER

The unit cell of FSS polariser is shown in Fig. 1. The FSS element is a cross dipole with different arm lengths in x- and y-directions. The lengths of the dipoles in x- and y- directions are 1.65 mm and 1.28 mm, respectively, while both are 0.1 mm wide. Rogers RO3003 [21] is used as a substrate having a

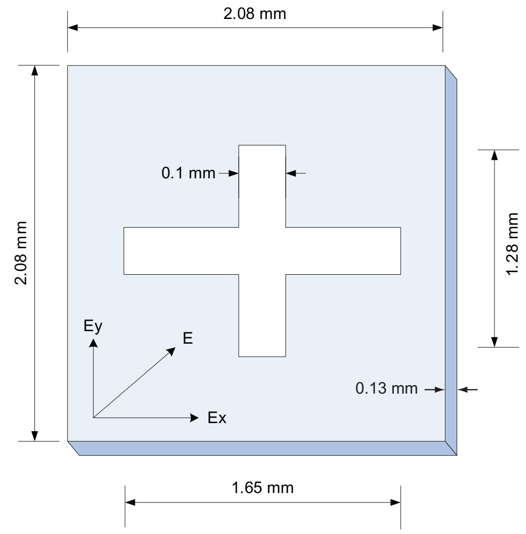

Fig. 1 The dimensions of the FSS unit cell with electrical field orientation

thickness of 0.13 mm. The dielectric constant and the loss tangent of the substrate are 3 and 0.0013, respectively. The periodicity of the unit cell in both directions is 2.08 mm.

III. SIMULATION SETUP

Time domain solver in CST Microwave Studio [22] is used for simulating the FSS unit cell with periodic boundary conditions. From the side where the wave is incident on the FSS surface, a plane wave port is defined with E-field tilted at 45º as shown in Fig. 2. This linear polarised wave titled at 45º can be decomposed in to its two orthogonal components in x- and y-direction as shown in Fig. 1. These Ex and Ey components are incident on arms of cross dipole having different lengths. This inturn acts as providing different refractive indexes in x- and y- direction and hence providing quarter-wave plate response. After passing through FSS polariser, the magnitude of Ex and Ey should be same at resonance frequency and there should be a 90º phase shift in between them to get a 100% circular polarisation.

To obtain the magnitude and the phase difference of two component of E-field after passing through the FSS polariser, the probes in CST MW Studio are used at the output to calculate the required parameters as shown in Fig. 3.

Once the simulation is completed, the template based post processing option is used to calculate the phase difference and the axial ratio while the transmission magnitudes can directly be determined from the probes.

IV. THEORETICAL RESULTS

In this section, the theoretical results of FSS polariser are presented. Fig. 4 shows the transmission magnitudes of the two components of E-field, i.e. Ex and Ey. The dipoles along x- and y-directions resonate at 66.9 GHz and 83.4 GHz,

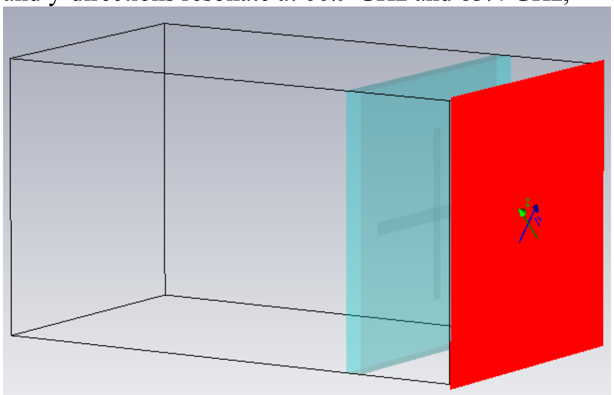

Fig. 2 Plane wave excitation with E-filed oriented at 45º

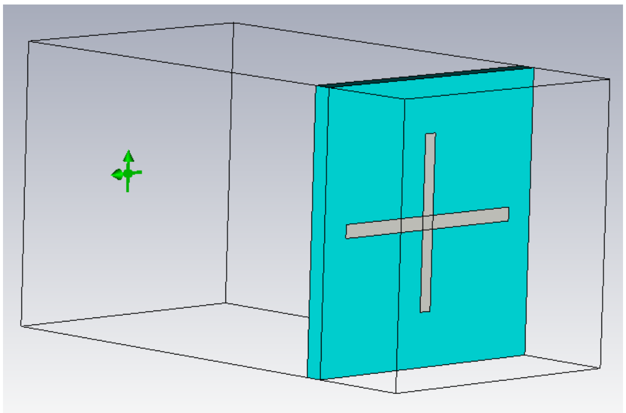

Fig. 3 Two probes shown in green colour at the output port

respectively. It can be noticed, that the magnitude of both electric fields is same at 75 GHz which is one of the requirements to convert linear polarisation to 100 % circular.

However, at frequencies above and below 75 GHz, the output tends to become elliptically polarised. It is worth mentioning here that the project for which this FSS polariser is designed, the main requirement is to convert linear polarised electromagnetic waves from the array of quasi-yagi antennas in to a rotational polarisation (which could be both circular and elliptical). Therefore, this particular FSS polariser can operate from 73-77 GHz frequency range having both circular and elliptical polarisation.

A transmission loss is also noticed due to the reflection from the FSS surface. Fig. 5 shows the transmission magnitudes of Ex and Ey in dB. At 75 GHz where the magnitudes of both the orthogonal electric field components are same, about 5.9 dB transmission loss can be noticed. This loss may affect the transmitted power through the polariser. This effect would be analysed during the measurement process.

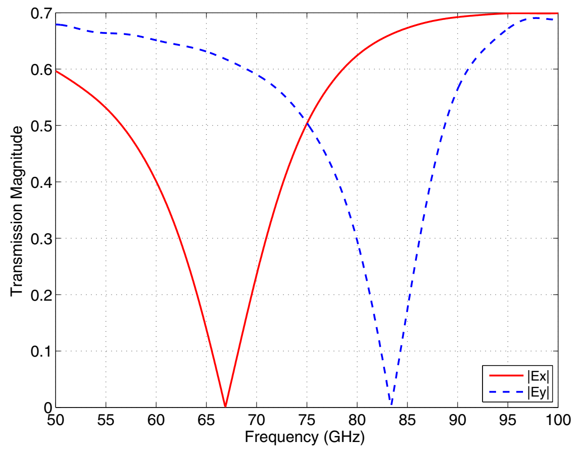

Fig. 4 Transmission magnitude of the orthogonal components of E-field

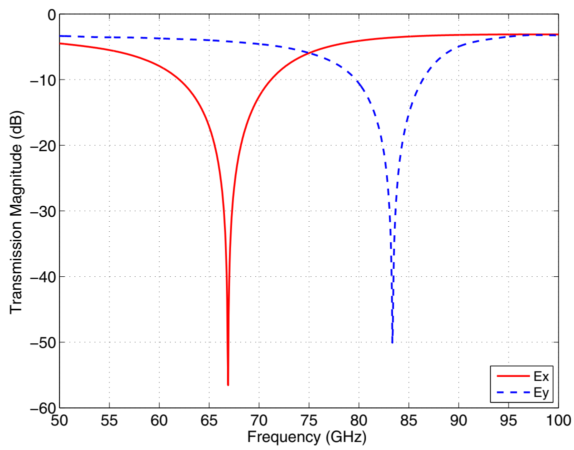

Fig. 5 Transmission magnitude (in dB) of the orthogonal components of E-field

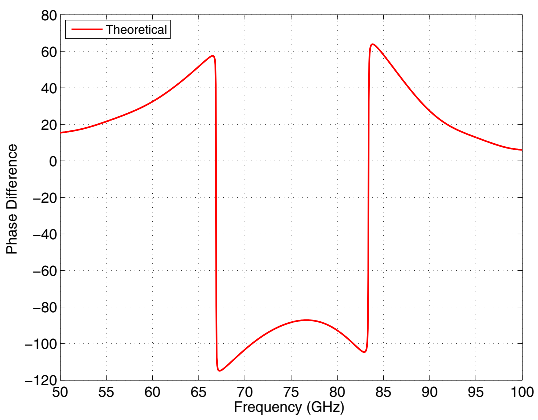

Fig. 6 Phase difference between the orthogonal components of transmitted E-field

For a quarter-wave plate to produce a perfect circular polarisation form linear, the phase difference between the two orthogonal components should be 90º. Fig. 6 shows the phase difference between the Ex and Ey components. At 75 GHz, the phase difference is about 89º giving rise to a 98% circular polarisation. The phase variation from 73-77 GHz is about 87º to 92º which is quite close to the desired value. However, with phase variation, there is also a change in the magnitudes of Ex and Ey, hence giving rise to elliptical polarisation as we move away from the centre frequency.

Another way to interpret the results is axial ratio. It is defined as the ratio of the minor to the major axes of polarisation ellipse [23]. As described before, in order to have an ideal quarter-wave plate, two criteria must be satisfied: a 90º phase shift and an axial ratio of 1. Fig. 7 shows the axial ratio of FSS polariser in which it can be seen that at 75 GHz, the value of axial ratio is about 0.98.

This means that at the centre frequency, about 98% circular polarisation is achieved. However, as we move toward side bands, the axial ratio starts to decrease giving rise to elliptical polarisation.

In the template based post processing option in CST, the following formulae have been used to calculate axial ratio:

Major Axis:

$$\sqrt{\frac{1}{2}\left[E_x^2+E_y^2+\sqrt{E_x^4+E_y^4+2E_x^2E_y^2\cos(2\delta_L)}\right]}$$

Minor Axis:

$$\sqrt{\frac{1}{2}\left[E_x^2+E_y^2-\sqrt{E_x^4+E_y^4+2E_x^2E_y^2\cos(2\delta_L)}\right]}$$

Where

δ_L= Phase difference between Ex and Ey

Therefore, axial ratio is given as:

AR = Minor Axis / Major Axis

It should be noted that the value of axial ratio varies from 0 to 1 (Fig. 7). If the value of axial ratio is 1, then it will be 100% circular polarisation and for 0 it will be 100% linear. In between 0 and 1, the polarisation will tend to be elliptical. Figure 8 shows the axial ratio in dB. The axial ratio is -0.24 dB at the centre frequency of 75 GHz, and above -2.5 dB in the frequency range 73 to 77 GHz.

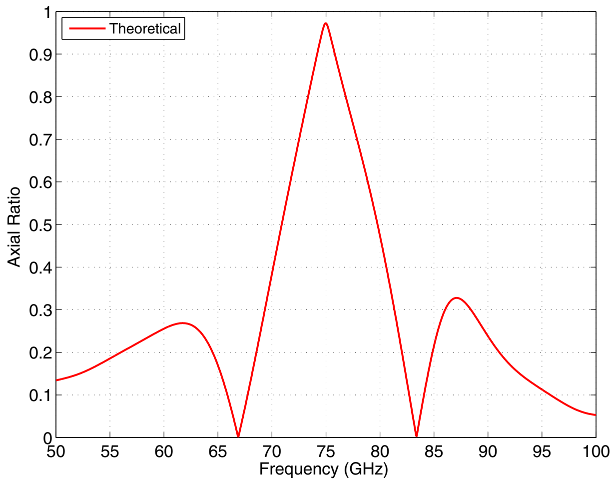

Fig. 7 Axial ratio of the transmitted E-filed components

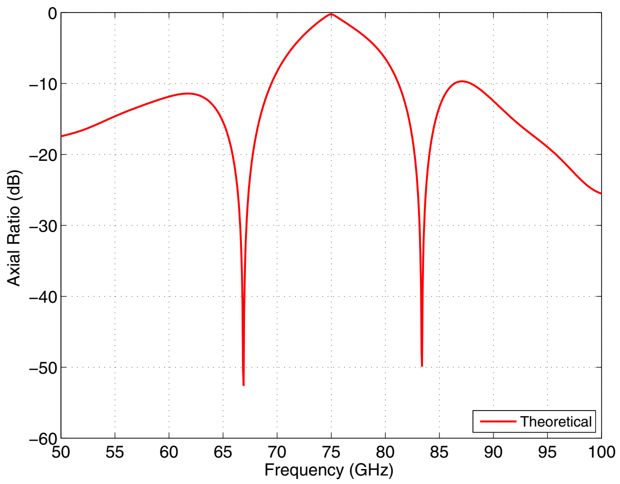

Fig. 8 Axial ratio in dB for transmitted E-filed components

V. CONCLUSIONS

A quarter-wave plate polariser based on frequency selective surface is presented. The design is quite simple and can be fabricated with ease. Therefore, the same principle may be used to design polarisers for other useful microwave and terahertz frequencies where a linear polarisation is required to be converted to circular/elliptical or vice versa. Future research will be focused on optimisation of a proposed birefringent polariser based on a frequency selective surface for an increased bandwidth and reduced propagation loss.

ACKNOWLEDGMENT

Many thanks to Dr Frank Demming of Computer Simulation Technology (CST) for his valuable help and support in modelling and simulating FSS polariser. Many thanks to Mr. Inam Faraz, a PhD scholar at Department of Physics and Engineering, Macquarie University Sydney, for valuable discussions related to the project.

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