

# FSS Based Circular Polarizer for High-Speed Wireless Communication at 75 GHz

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## Abstract

An FSS based circular polarizer for high-speed wireless communication at 75 GHz is presented. It has been designed on a low loss substrate with cross-dipole elements. Both simulation and measured results showed more than 98% circular polarization at 75 GHz. Moreover, 3 dB axial-ratio bandwidth of 6.8 GHz (Simulation) and 7.8 GHz (Measured) has been achieved. The proposed design has many advantages over the recently published research such as simplicity, low-profile, percentage bandwidth, frequency of operation and relative insertion loss.

## Keywords

Circular Polarization, Frequency Selective Surface, High Frequency Communication, Linear Polarization

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## 1. Introduction

The communication in circular polarization mode is very important in tracking and radar communication applications. It has many advantages and disadvantages to linear polarization. Some of these have lesser effect of absorption from atmosphere, multi-path fading and reflection from different sources. Moreover, in applications where the polarization is continuously changing or its tilt is not known, linear polarization cannot be used.

For inter-aircraft communications or wireless communication between mobile nodes, using circular polarization is an advantage. One way of achieving circular polarized wave communication is the use of electronically steerable antenna arrays [1] [2]. However, design and development of such systems in which electronic circuitry needs to be integrated with arrays of antennas is a challenge [3] [4]. Moreover, most of such antenna systems provide linear polarization [5] [6]. A solution to this problem is to design and develop a linear polarized an-

tenna array and incorporate a linear to circular polarizer as a front-end. Dielectric polarizers [7], meander-line [8] [9] [10] and grid-plate polarizers [11] have been proposed to convert linear polarized electromagnetic waves to circular.

The use of FSS in many applications such as waveguides, antenna radomes, RCS reduction, wireless security, transmission improvement in energy-saving buildings and other communication applications is very popular [12]. For applications in which the linear polarization is required to convert into circular polarization as mentioned earlier, FSSs can be used to achieve this goal due its simple design and ease of fabrication [13]-[18].

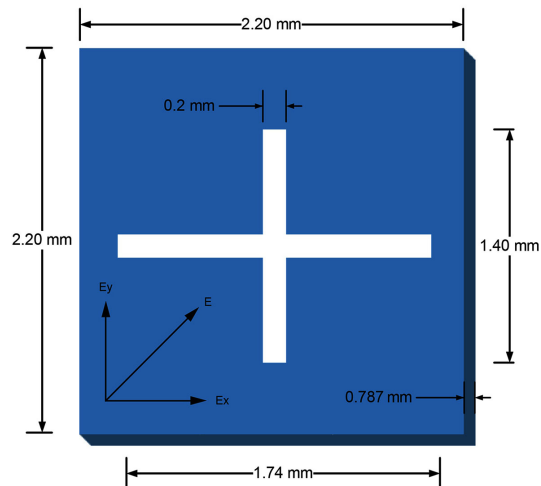
This paper presents a single layer FSS linear to circular polarizer which can be used for high-frequency communication applications at 75 GHz. It is based on a simple cross-dipole FSS element. The linear to circular polarization is achieved by non-equally varying the length of dipoles in x and y directions. Both simulation and measured results show more than 98% circular polarization at 75.2 GHz. Moreover, 3 dB axial-ratio bandwidth of 6.8 GHz (Simulation) and 7.8 GHz (Measured) is achieved.

Cross-dipole, Jerusalem cross-dipole and other structures have been used for linear to circular polarization conversion in the recent research [13]-[20], however, either these designs are for much lower frequencies with lesser percentage bandwidth or multi-layer structures adding complexity to the design. Moreover, most of these researches present simulation results only. For example in [13] a planar dual-band linear to circular polarization converter using radial-shape multi-layer FSS has been presented. Despite being dual-layer structure which adds complexity, the insertion loss is quite high and the cumulative bandwidth of both bands is not wide. Also, no measured data has been provided to validate the simulation results. Reference [14] also presents a complex design with more than 3 dB insertion loss which should be lower than that as expected in multi-layer designs, especially at frequencies much lower than the one presented in this paper. The FSS design presented in [16] is single layer operating at 30 GHz with more than 4 dB insertion loss at the centre frequency which is quite high considering the frequency of operation. Same issues can be noticed in [16] [17] [18] [19] [20].

The proposed FSS polarizer is designed to use as a front end of a linear polarized antenna array operating at 75 GHz for inter-aircraft communication applications. It required a simple, low-profile design having an acceptable insertion loss and high bandwidth. Both simulation and measured data are presented as well.

## 2. Polarizer Design

**Figure 1** shows the unit cell of FSS polarizer. The dimensions of the length of dipoles in two directions are 1.74 (x-) mm and 1.40 mm (y-), respectively; with a width of 0.2 mm. Rogers RT5880 having a thickness of 0.787 mm is used in the design [21]. Its dielectric constant is 2.2 while the loss tangent is 0.0009. The dimension of the unit cell in both directions is 2.20 mm.



**Figure 1.** FSS unit cell with orientation of electrical field.

### 3. FSS Simulation Setup

CST Microwave Studio 2017 is used to setup simulation of FSS polarizer shown in **Figure 1** [22]. The time domain solver with periodic boundary condition is applied to the unit cell. A plane wave port is defined with E-field tilted at  $45^\circ$  at the side where the wave is incident on the FSS surface as shown in **Figure 2**. This linear polarized wave is incident with a tilt angle of  $45^\circ$  such that it will decompose into its two orthogonal equal magnitudes in-phase components in both directions as shown in **Figure 1**. The  $E_x$  and  $E_y$  components are incident on the different length arms of the cross dipole. For obtaining a perfect circular polarization, there should be a  $90^\circ$  phase difference between  $E_x$  and  $E_y$  components and their magnitude should be same. The phase difference and magnitude of E-field are obtained using CST MW Studio 2017 optimization tool [22].

Once the simulation is completed, the template-based post processing option in CST MW Studio is used to calculate the axial ratio. The following formulae have been used to calculate axial ratio [23]:

Major Axis:

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

Minor Axis:

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

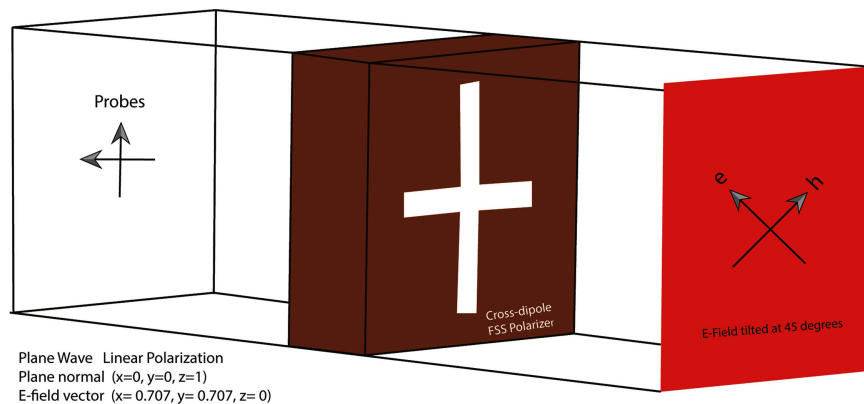
where

$\delta_L$  = The phase difference between electric field components in  $x$  - and  $y$ - directions

With axial ratio given as:

$$AR = \text{Minor Axis} / \text{Major Axis}$$

The value of axial ratio can vary from 0 to 1. If the value of axial ratio is 1, then it will be 100% circular polarization and for 0 it will be 100% linear. In between 0 and 1, the polarization will tend to be elliptical.



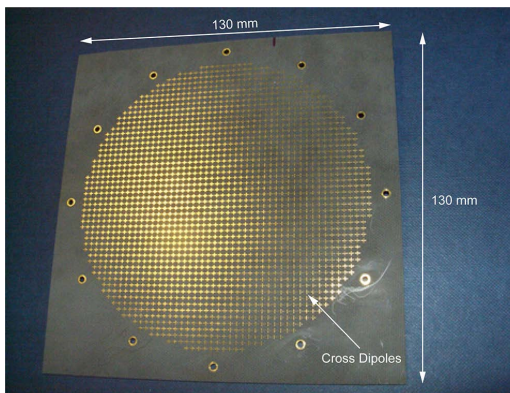
**Figure 2.** Plane wave excitation with E-field oriented at  $45^\circ$  with two probes shown in green color at the output port.

#### 4. Fabrication and Measurement Setup

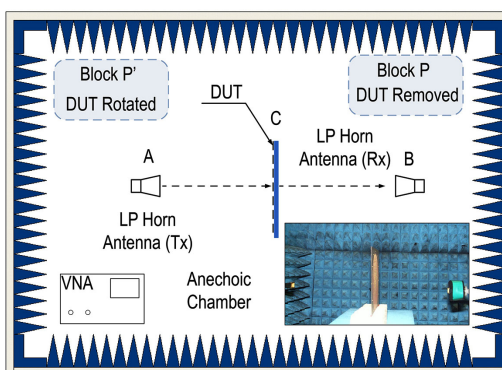
The FSS polarizer implementing unit cell shown in **Figure 1** was fabricated and is shown in **Figure 3**. The dimension of the prototype is  $130 \text{ mm}^2$ . The FSS consists of cross-dipoles uniformly populated within a circular area (114 mm diameter). The block diagram of the measurement setup is depicted in **Figure 4** while the inset shows its photograph. A pair of HP 85104A test set modules in conjunction with an HP 86105A mm-wave controller is needed with the HP 85106D Network Analyzer System to make the S-parameters measurements at mm-wave frequencies. The FSS polarizer prototype was tested using standard-gain V/W-band horn antennas as shown in **Figure 4**. The transmitter horn antenna which is linearly polarized (Tx) is fed from the VNA which is at a distance of 265 mm (V-band)/185mm (W-band) away at a normal angle to the surface of prototype. There is an equal distance of receive antenna (Rx) from the surface of prototype. The vertical and horizontal polarizations are achieved by relative rotation of the x-y aligned DUT by  $90^\circ$ . To obtain the transmission phase/magnitude in the far field, the values are normalized with respect to a similar measurement setup without the FSS polarizer array. The measurements are done in an anechoic chamber.

#### 5. Results

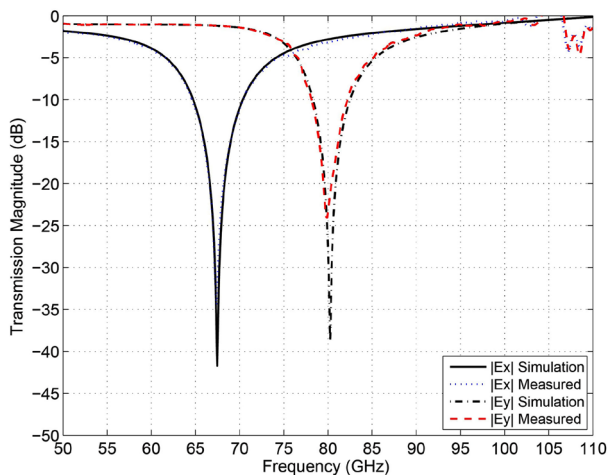
Both measured and simulation results are shown in this section. **Figure 5** shows the transmission magnitudes (in dB) of  $E_x$  and  $E_y$  components of E-field. The dipoles along x- and y-directions resonate at 67.3 GHz and 80.2 GHz, respectively. The two responses intersect at 75.2 GHz. Here the magnitude of both electric fields is the same, and the phase difference between them is about  $89^\circ$ . However, at frequencies above and below this frequency, the output tends to become elliptically polarized. A transmission loss of 4.8 dB is also noticed due to the reflection from the FSS surface. This loss can be further reduced by designing dual-layer structures using the Fabry-perot concept but adds complexity to the design [23].



**Figure 3.** The photograph of the transmission polarizer with dimensions.



**Figure 4.** Block diagram of the measurement setup while its photograph is shown in inset.

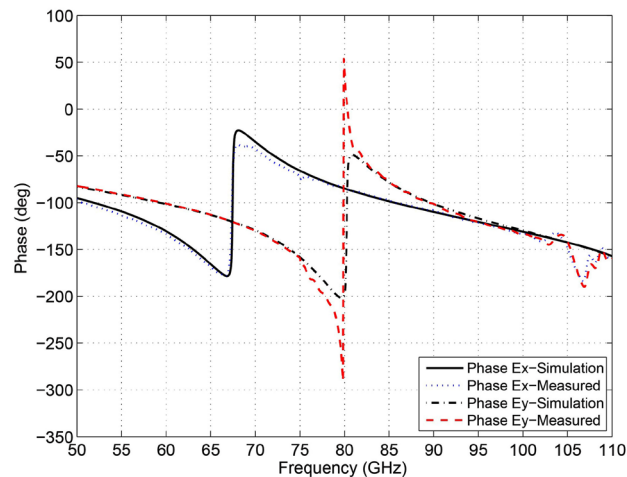


**Figure 5.** The Simulation and measured transmission magnitudes of Ex and Ey.

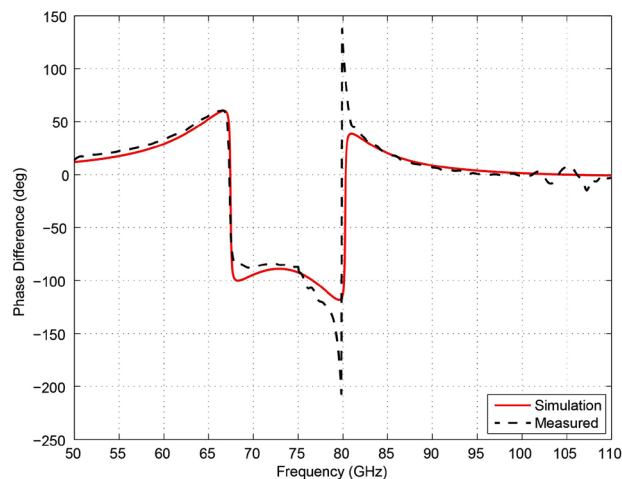
**Figure 6** shows the phase of the Ex and Ey components. For Ex component, both measured and simulation results depict good agreement while for Ey component, measured results show variation at around 80 GHz. **Figure 7** shows the difference in phase between two components of E-field. At 75.2 GHz, the phase

difference is about  $89^\circ$  giving rise to a 98% circular polarization. In simulation, the phase variation from 75.2 GHz to 80.3 GHz is about  $87^\circ$  to  $92^\circ$  which is quite close to the desired value of  $90^\circ$ . However, with phase variation, there is also a change in the magnitudes of  $E_x$  and  $E_y$ , hence giving rise to elliptical polarization as we head away from the center frequency. The phase for both simulation and measured results is same at 75.2 GHz, however, within the band of interest there is a small difference in the results which could be due to measurement inaccuracy and fabrication tolerances.

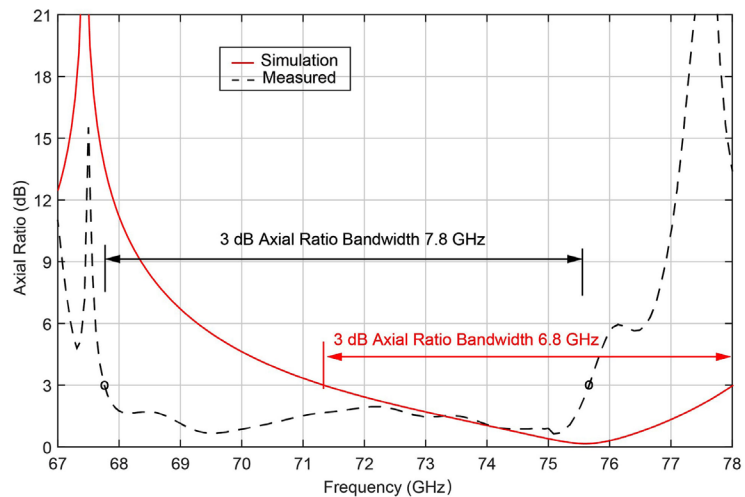
**Figure 8** shows the axial ratio in dB. In case of simulation results, a 3 dB bandwidth of 6.8 GHz (72.2 GHz to 78 GHz) is achieved, while the measured results show a bandwidth of 7.8 GHz (67.8 GHz to 75.6 GHz). The difference in the results is due to measurement inaccuracy in phase of  $E_x$  and  $E_y$  components. However, from 72 GHz to 75 GHz, there is a good agreement between simulation and measured axial ratio, giving a bandwidth of 3 GHz.



**Figure 6.** Simulation and measured transmission phase difference between  $E_x$  and  $E_y$  components.



**Figure 7.** Simulation and measured transmission phase difference of the orthogonal components of E-field.



**Figure 8.** Simulation and measured axial ratios for transmitted E-filed components.

## 6. Conclusion

A simple FSS polarizer is presented for high-speed wireless communication at 75 GHz. The design is quite simple and can be fabricated with ease. The 3 dB axial ratio bandwidth of 6.8 GHz (9%) and 7.8 GHz (10.4%) has been achieved in simulation and measurements, respectively. It can be used as a linear to circular polarizer in inter-aircraft communication to resolve the complexity of designing circular polarized antennas as front end. Due to the reflections from polarizer surface and loss in the dielectric, there is a transmission loss of 4.8 dB which can be considered acceptable for a single layer polarizer operating at high frequency. The specifications of the proposed design are unique compared to the recent researches. However, research is underway to reduce the insertion loss further, achieve stable oblique incidence performance and improve 3 dB axial ratio bandwidth. Different FSS elements and low-loss substrates are being investigated.

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## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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