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## Circular Polarization Frequency Selective Surface Operating in Ku and Ka Band

Robert Orr, Vincent Fusco, Dmitry Zelenchuk, George Goussetis, Elena Saenz, Massimiliano Simeoni, and Luca Salghetti Drioli

**Abstract**—A double layer Circular Polarization (CP) Frequency Selective Surface (FSS) for use as a dual band quasi-optical diplexer suitable for deployment in reflector antenna systems is described. The FSS was designed to reflect Ku band signals (11.7 – 12.75 GHz) while transmitting Ka band signals (17.3 – 20.2 GHz) and conserving CP in each of these bands. The simulated/measured reflection loss over the Ku band was less than 0.05 dB/0.1 dB for both TE and TM polarizations while the simulated/measured axial ratio was less than 0.2 dB/0.75 dB. Over the Ka band the simulated/measured transmission loss for both polarizations was below 0.25 dB/0.4 dB and the simulated/measured axial ratio was less than 0.25 dB/0.75 dB. To the best of our knowledge this is the first report of a metallo-dielectric FSS that simultaneously operates in CP for an oblique angle of incidence in both Ku and Ka bands.

**Index Terms**—Circular Polarized FSS, Ka-Ku Band, satellite communications.

### I. INTRODUCTION

FREQUENCY Selective Surfaces (FSS) have been used as frequency diplexers in satellite reflector antenna systems with feeds placed on either side of the FSS [1]-[3]. In this configuration the FSS is designed to be reflective for one of the feeds, thus acting as a sub-reflector, while for the other it is transparent allowing the feed to be placed at the focal point of the main reflector, see Fig. 1. Both feed antennas can therefore utilize the same main reflector. This is a method by which the communication capacity of the antenna system can be increased while reducing the mass and volume of the satellite payload.

The recent trend in satellite systems is towards operation in Circular Polarization (CP), which is advantageous in communication and sensing systems as it provides resilience to effects such as Faraday rotation [4] and rain clutter [5] while also removing the requirement for polarization alignment between the transmitter and receiver. In conjunction with the ever increasing demand for higher throughput, as e.g. highlighted by the trend towards multibeam satellite communications coverage, these developments bring to fore the need for a quasi-optical FSS diplexer that operates in CP as identified in e.g. [6].

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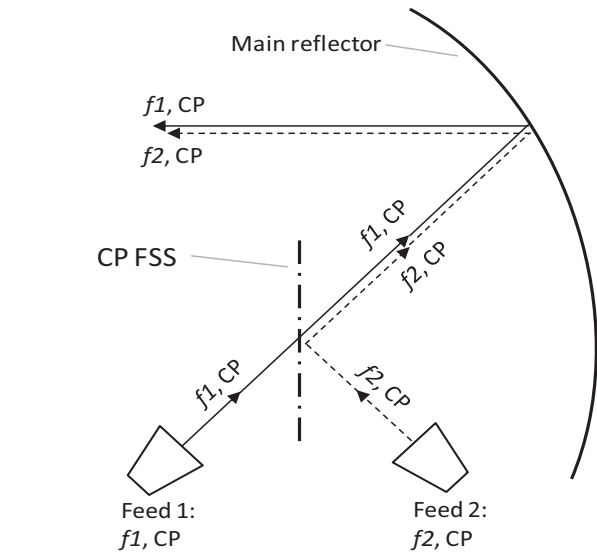


Fig. 1. Circular Polarization (CP) Frequency Selective Surface (FSS) applied as a quasi-optical diplexer in a satellite reflector antenna system. CP feeds 1 and 2 placed on either side of the FSS utilize the same main reflector.

Recently there has been much interest in the design of polarization independent frequency selective surfaces. These surfaces have near identical reflection and transmission coefficient magnitudes for TE and TM polarized waves. Several FSS geometries with such properties have been presented including crossed dipoles [7], Jerusalem cross apertures [8], conducting rings [9], double square loop arrays and gridded double square loop arrays [10]. FSS consisting of an array of nested slots have recently been developed for the detection of dual-polarized radiation in passive remote sensing space science instruments [11]-[12]. Such FSS elements made up of a pair of nested shorted annular slots allow independent control of the spectral response for TE and TM polarizations at oblique angles of incidence.

In a CP quasi-optical diplexer, CP should be maintained in both the reflection and transmission bands. Consequently the FSS reflection/transmission coefficient (both magnitude and phase) should be equal for the TE and TM polarizations. For plane waves incident in the direction normal to a planar FSS, the geometrical symmetry ensures co-incident magnitude and phase responses for the two principal linear polarizations. However the symmetry breaks for the case of obliquely incident waves, as would be required to address the scenario depicted in Fig. 1. While the designs in [7]-[12] focus on ensuring that reflection and transmission magnitude are equal for obliquely incident TE and TM polarized waves, their phase properties are not considered and therefore the conservation of CP upon reflection and transmission cannot be guaranteed.

In this paper we report the first metallo-dielectric FSS that operates in CP. The presented FSS design is suitable for use as

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a quasi-optical CP diplexer and meets the typical frequency plan of a modern satellite communication system. In particular the FSS reflects signals occurring in the Ku band (11.7 – 12.75 GHz) and transmits those in the Ka band (17.3 – 20.2 GHz). Conservation of the CP signal is achieved simultaneously in both the reflection/transmission bands by ensuring that the reflection/transmission magnitude and phase are as near equal as possible for TE and TM polarizations over the respective operating bands.

## II. SIMULATED AND MEASUREMENT RESULTS

Double square loop FSS elements [13]-[15] were utilized in the FSS design. This element type was favored as it allows for independent tuning of the reflection and transmission bands by modifying the dimensions of the relevant loop. Furthermore, they provide good angular stability and allow the elements to be packed closely together with enhanced bandwidth. Our investigations (not shown here for brevity) have demonstrated that although single layer FSS designs can produce CP response, the bandwidths that they can achieve are too narrow for the frequency plans of typical Ku-/Ka-band satellite communication systems. Therefore a double layer FSS array design has been selected.

The FSS consists of two arrays of copper double square loop elements, each patterned on a Taconic Fastfilm27 substrate (thickness = 56  $\mu\text{m}$ , permittivity,  $\epsilon_r = 2.7$ , loss tangent,  $\tan\delta = 0.0012$ ). These substrates were bonded using spray glue on either side of a sheet of Rohacell foam (thickness = 5 mm, permittivity,  $\epsilon_r = 1.06$ , loss tangent,  $\tan\delta = 0.0008$ ) with the conductor patterns facing outwards. The spray glue has negligible effect on electromagnetic performance.

The simulation and design of the FSS was carried out using CST Microwave Studio (MWS) [16]. A unit cell of the array was created and the y- and x- boundaries were set to unit cell implying that the array was of infinite size. Floquet ports were established at the z-boundaries and the angle of incidence was set to  $45^\circ$ . Displayed in Fig. 2 is the unit cell of the FSS design with dimensions identified. This unit cell pattern is repeated, with different dimensions, on both the top and bottom of the two layer design. Parametric analyses were carried out to realize the identified design requirements. LP excitation (in terms of the typical definition of TE and TM modes) was used in the design process as this allowed for more insight on the tuning of the geometrical parameters. Referring to Fig. 2 the optimized dimensions of the design are listed in Table I.

The axial ratio was generated from the simulated reflection and transmission coefficients using the expression in [17]. The reflection coefficient (magnitude and phase) for TE and TM polarizations was used to calculate the Ku band axial ratio while the transmission coefficient (magnitude and phase) for TE and TM polarizations was used for the Ka band axial ratio. The Ku band and Ka band axial ratios show how the CP of the incoming wave has been affected by reflection from the structure and transmission through the structure respectively. Our simulations have demonstrated that the cross-polarization reflection and transmission coefficients are below -50dB compared to the co-polar coefficients and therefore have

negligible impact in the AR estimation.

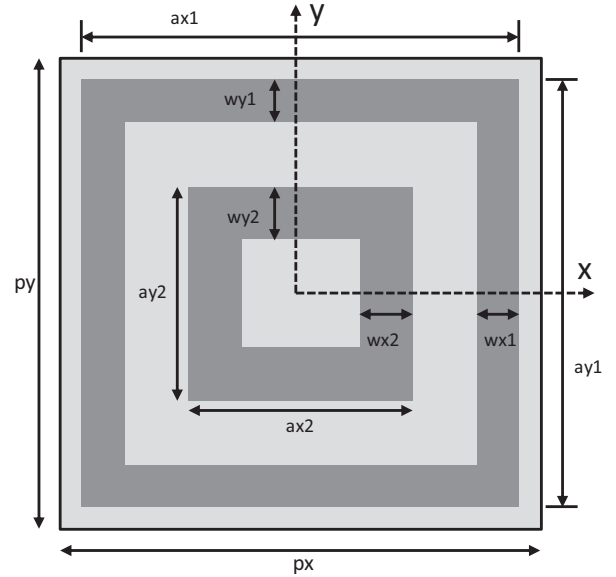


Fig. 2. A unit cell of the top/bottom FSS pattern with key dimensions identified.

TABLE I  
DIMENSIONS FOR THE DOUBLE LAYER FSS – TOP AND BOTTOM ARRAYS – AFTER OPTIMIZATION WITHIN CST MWS

Top Array		Bottom Array	
Parameter	Value (mm)	Parameter	Value (mm)
$p_x$	6.79	$p_x$	6.79
$p_y$	6.76	$p_y$	6.76
$a_{x1}$	6.45	$a_{x1}$	6.33
$a_{y1}$	6.09	$a_{y1}$	6.22
$a_{x2}$	4.00	$a_{x2}$	3.72
$a_{y2}$	3.45	$a_{y2}$	3.39
$w_{x1}$	0.37	$w_{x1}$	0.37
$w_{y1}$	0.45	$w_{y1}$	0.44
$w_{x2}$	1.29	$w_{x2}$	1.07
$w_{y2}$	1.01	$w_{y2}$	0.58

Fig. 3a shows the prototype of the double layer FSS with the top array visible. Fig. 3b and Fig. 3c display zoomed in views of the top and bottom of the FSS respectively with individual array elements visible. The overall array is approximately 305 mm by 305 mm (330 mm x 330 mm including mounting margin) in size which equates to 45 x 45 unit cells. Alignment holes marked on the array margins are used for top/ bottom pattern registration. Misalignment between the two layers was less than 0.3 mm.

The double layer FSS was measured to verify the simulation results. A two-port measurement Vector Network Analyzer (VNA) setup was used to measure the FSS complex transmission and reflection coefficient. The measurement arrangement consisted of two linearly polarized square pyramidal standard gain horn antennas titled  $45^\circ$  to the vertical axis. Two different sets of horn antennas were used; 11.5 – 18 GHz which included the Ku band (11.7 – 12.75 GHz) and 17.2 – 27 GHz which included the Ka band (17.3 – 20.2 GHz). The FSS was supported by a stand and surrounded by radar

absorbing material (RAM). The distance between each horn antenna and the FSS was chosen to ensure the array was in the far field. When measuring 11.5 – 18 GHz this distance was 106 cm while for 17.2 – 27 GHz it was 75 cm.

The complex transmission coefficient is measured using the horn antennas with the FSS in place and then normalized with respect to an identical measurement where the FSS has been removed. The complex reflection coefficient was measured by placing both horn antennas on the same side of the FSS each at an angle of  $45^\circ$  from the normal. In this case the measurement was normalized with the FSS replaced with a metallic plate of the same dimensions. With both horn antennas vertically polarized co-polar TE incidence was measured. Rotation of both antennas by  $90^\circ$  allowed measurements for co-polar TM incidence to be obtained. The simulated cross-polar components were also validated with measurement results. For cross-polar reflection and transmission measurements one horn antenna was vertically polarized while the other was horizontally polarized (rotated by  $90^\circ$ ). The co-polar reference measurements were used in the cross-polar measurements.

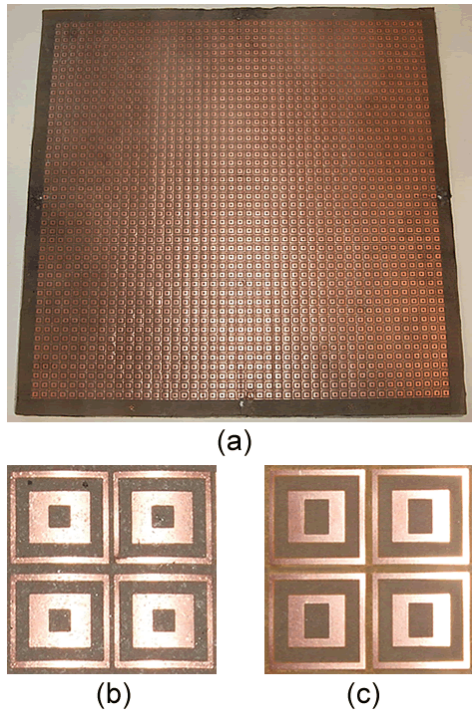


Fig. 3. Prototype of double layer FSS (a) sample of size approximately 330 x 330 mm with top array visible. Zoomed in view of (b) the top array and (c) the bottom array with individual FSS elements visible.

Fig. 4 displays the simulated and measured reflection magnitude (TE and TM polarizations) and axial ratio of the double layer FSS over the frequency range 11.5 – 15 GHz. In Fig. 5 the transmission magnitude (TE and TM polarizations) and transmission axial ratio from simulations and measurements over the frequency range 17.2 – 21.2 GHz is plotted. There is good agreement between simulation and measurement results. The measured reflection loss over the Ku band (11.7 – 12.75 GHz) for both polarizations is less than 0.1 dB and the measured reflection axial ratio is less than 0.75 dB. Over the Ka band (17.3 – 20.2 GHz) the measured transmission

loss for both polarizations is less than 0.4 dB and the measured transmission axial ratio is less than 0.75 dB.

In Fig. 4 it can be seen that the measured TE and TM reflection magnitude is at some frequencies greater than 0 dB. It is thought that when measuring the FSS, focusing effects caused by e.g. edge diffraction lead to an increased signal reception and hence the observed result. A similar effect was identified in [18] when measuring double layer dipole and tripole arrays. Confirming our simulation results, we further note that inclusion of the cross-polar components (not reported here for brevity) has virtually no effect on the reflection and transmission axial ratios as the measured cross-polar levels were in all cases below -30 dB.

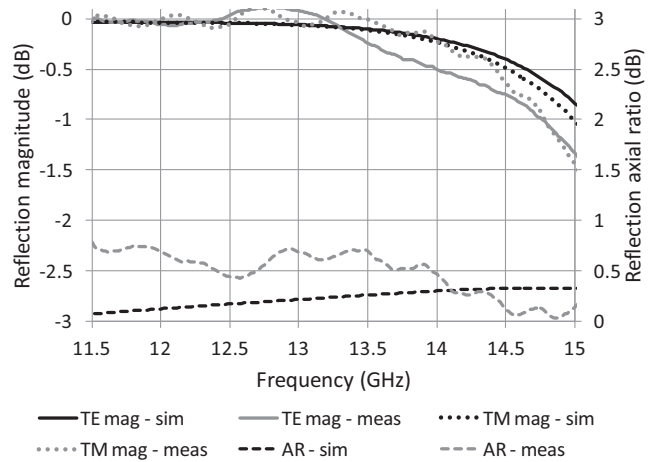


Fig. 4. Simulated and measured reflection magnitude (TE and TM polarizations) and reflection axial ratio - double layer FSS for plane waves incident at  $\theta = 45^\circ$  - 11.5 – 15 GHz.

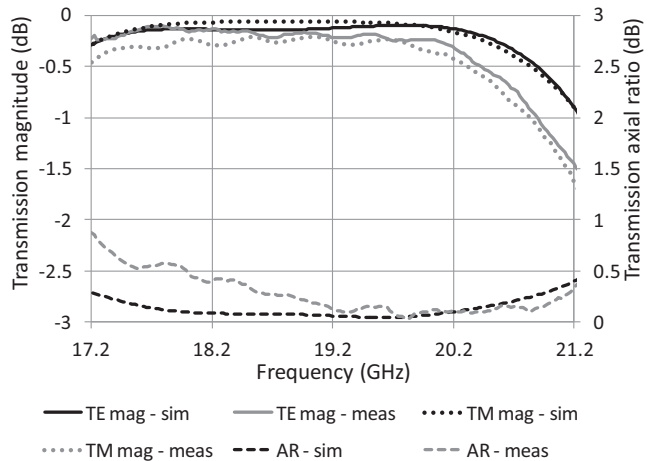


Fig. 5. Simulated and measured transmission magnitude (TE and TM polarizations) and transmission axial ratio - double layer FSS for plane waves incident at  $\theta = 45^\circ$  - 17.2 – 21.2 GHz.

An angular stability analysis was completed based on simulations. For each incidence angle ( $30^\circ$ ,  $40^\circ$ ,  $45^\circ$ ,  $50^\circ$ ,  $60^\circ$ ) the reflection loss in the Ku band for TE and TM polarizations was less than 0.1 dB while the transmission loss in the Ka band was less than 0.4 dB for both polarizations. Maximum axial ratio in Ku and Ka bands band is shown in Table II for the



different incidence angles. In each band the axial ratio is less than 3dB for all incidence angles.

TABLE II  
ANGULAR STABILITY ANALYSIS FOR DOUBLE LAYER FSS – MAXIMUM REFLECTION AND TRANSMISSION AXIAL RATIO IN THE KU AND KA BANDS

Incidence angle (deg)	Maximum axial ratio (dB)	
	Ku band (11.7-12.75 GHz)	Ka band (17.3-20.2 GHz)
30	0.35	1.45
40	0.1	0.5
45	0.2	0.25
50	0.45	0.9
60	1.2	3.0

### III. CONCLUSION

A double layer Circular Polarization (CP) Frequency Selective Surface (FSS) was designed for use as a quasi-optical diplexer in a reflector antenna system with feeds placed at either side. The diplexer was designed for upcoming satellite communications applications utilizing the Ku band (11.7 – 12.75 GHz) and the Ka band (17.3 – 20.2 GHz) that need to conserve CP in each of these bands.

The double layer FSS was fabricated, assembled and measured. Measurement results agreed well with simulations and show sufficiently good performance. The design proposed in this paper should open the way for more compact satellite communications capable of deployment for next generation Ku/Ka band communication relay applications.

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