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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 frequencySplitters 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].

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 incidence 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...
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 µm, permittivity, $\varepsilon_r = 2.7$, 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, $\varepsilon_r = 1.06$, 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°. 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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mm)</th>
<th>Parameter</th>
<th>Value (mm)</th>
</tr>
</thead>
<tbody>
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<td>$p_x$</td>
<td>6.79</td>
</tr>
<tr>
<td>$p_y$</td>
<td>6.76</td>
<td>$p_y$</td>
<td>6.76</td>
</tr>
<tr>
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<tr>
<td>$w_{y1}$</td>
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<td>$w_{y2}$</td>
<td>1.01</td>
<td>$w_{y2}$</td>
<td>0.58</td>
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</table>

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° 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° 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° 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°). The co-polar reference measurements were used in the cross-polar measurements.

Fig. 3 displays the simulated and measured reflection magnitude (TE and TM polarizations) and reflection 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.

An angular stability analysis was completed based on simulations. For each incidence angle (30°, 40°, 45°, 50°, 60°) 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>
<thead>
<tr>
<th>Incidence angle (deg)</th>
<th>Maximum axial ratio (dB)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Ku band (11.7-12.75 GHz)</td>
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<tr>
<td>30</td>
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</tr>
<tr>
<td>40</td>
<td>0.1</td>
</tr>
<tr>
<td>45</td>
<td>0.2</td>
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<tr>
<td>50</td>
<td>0.45</td>
</tr>
<tr>
<td>60</td>
<td>1.2</td>
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</table>

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.

REFERENCES