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An improved topology for reconfigurable CPSS-based reflectarray cell

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***Abstract*— An improved topology of a CPSS-based unit-cell is proposed as a building block of reconfigurable dual-CP reflectarrays in X-band. Its performance is first studied numerically under oblique incidence. Then, we show that it is possible to reduce significantly the number of active components needed to reconfigure the unit-cell, thus leading to an easier implementation.**

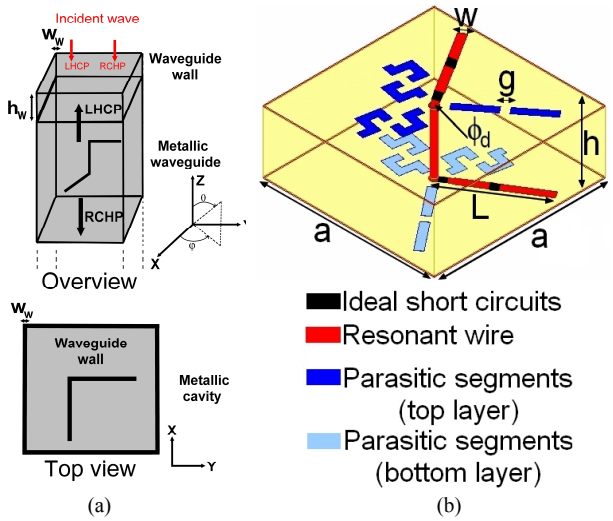
Index Terms*— *Reflectarray; Circular polarisation selective surface; Unit-cell.

I. INTRODUCTION

Reconfigurable reflectarrays are very attractive for beam scanning or beam-shaping in space applications such as Earth observations and satellite communications. They combine the benefits of active phased arrays and reflector antennas for the design of high-performance multiple-beam antenna systems. In order to achieve higher data rate transmissions and prevent from losses due to polarisation misalignment, circular polarisation (CP) is usually preferred. Several circularly-polarised reflectarray unit-cells in frozen states have been proposed in the literature [1], [2], but they only operate with one single CP wave. To our best knowledge, reconfigurable dual-CP unit-cells with independent control of the reflected phases in both polarisations have never been studied so far.

A dual-layer unit-cell including a circular polarisation selective surface (CPSS) has been proposed in [3], [4] as an attractive building block for dual-CP reconfigurable reflectarrays. Here we focus our attention on the first layer only. The corresponding Left-Handed CPSS (LH-CPSS), derived from the Pierrot's cell [5], is depicted in Fig. 1a. It consists of a 1λ-long resonant wire, folded into 3 segments. The horizontal segments (along x and y-axes) are 3λ/8-long and are connected by a λ/4 central vertical segment (along z-axis). The electric currents induced on both horizontal segments by a normally incident wave add either in phase (in this case, the LHCP incident wave is reflected) or out of phase (the RHCP incident wave is transmitted). The unit-cell is embedded in a square metallic waveguide.

To achieve four phase states, four different configurations of the horizontal segments with appropriate rotation angle are needed. In the future version of the active cell, switches (e.g. MEMS) will be used to connect or disconnect the different metallic parts forming a resonant wire. As a first step towards this objective, only frozen states are considered here: switches in the *on*- and *off*-states are replaced by ideal short and open circuits respectively. One of the four cell configurations is represented in Fig. 1b. The active resonant wire is shown in red, while the three passive ones are shown in blue. This unit-cell provides a high isolation between the two incident circular polarisations and almost a 2-bit phase resolution of the reflected LHCP polarisation [3], [4].



(a) (b)

Fig. 1. (a) Schematic representation of the LH-CPSS unit-cell. The four edges of the cell are PEC wall forming a metallic cavity: w_w=0.1mm, h_w=20mm. (b) One of the four cell configuration: a=22.88mm, w=1mm, h=8.49mm, g=1mm, L=12.1mm, ϕ_d=0.8mm.

In this paper, further investigations are carried out in order to progress towards an actual reconfigurable cell. First, the effect of incidence is studied using a more realistic cavity-backed configuration (Section II). Second, the initial cell geometry of Fig. 1b is modified so as to reduce the total number of phase controls. This will lead to a simpler fabrication and a reduction of loss and parasitic effects of biasing circuitry (Section III).

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II. Performance under oblique incidence

In [3], the cell was studied in a waveguide simulator. Here the effect of incidence is studied using a more realistic configuration: a metallic grid extends the metallic waveguide above the cell, as represented in Fig. 1a. It is well known that Pierrot's cell [5] is very sensitive to incidence angle. For our configuration, the dependency to incidence angle is mainly governed by the reflection at the waveguide mouth. Figs. 2 and 3 show the simulated performance of the unit-cell in LHCP reflection ($|\Gamma_{L\text{-}L}|$ (magnitude)) and RHCP transmission ($|T_{R\text{-}R}|$ (magnitude)) for the same phase state as the one shown in Fig. 1b. These scattering parameters have been computed for various incidence angles θ in plane φ=0° using periodic boundary conditions and Floquet ports in HFSS. The results are given for the centre frequency (8.5GHz) and at the band edges (8.2 and 8.7GHz).

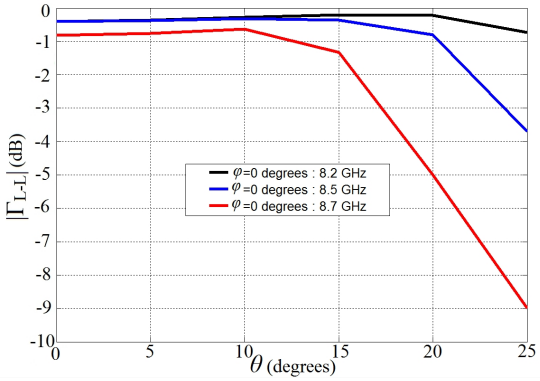


Fig. 2. Simulated magnitude of the reflection coefficient in LHCP for various incidence angles θ (in the φ=0° plane) at three frequency points.

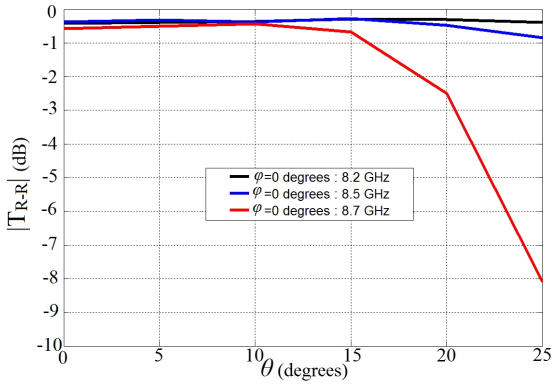


Fig. 3. Simulated magnitude of the transmission coefficient in RHCP for various incidence angles θ (in the φ=0° plane) at three frequency points.

In the simulations, the thickness w_w of the waveguide wall (Fig. 1a) is 0.1mm, and the height h_w of the metallic grid is set to 20mm (no optimisation has been done yet regarding these parameters). As can be seen, the insertion loss remains lower than 1 dB for θ lower than 15° over the whole bandwidth in reflection and transmission. For θ>15°, the unit-cell exhibits good performance until 8.5 GHz. In this case, using a large *F/D* ratio or a facetted configuration (as done in [6]) would be necessary to limit the maximum value of the incidence angle. Alternatively, advanced CPSS geometries could be used as described recently in [7]. Figs. 4 and 5 show the simulated performance of the unit-cell in LHCP reflection and RHCP transmission for the same phase state with scattering parameters computed for various incidence angles θ in plane φ=30°. The reflection at the waveguide mouth is better for φ=30° than for φ=0°.

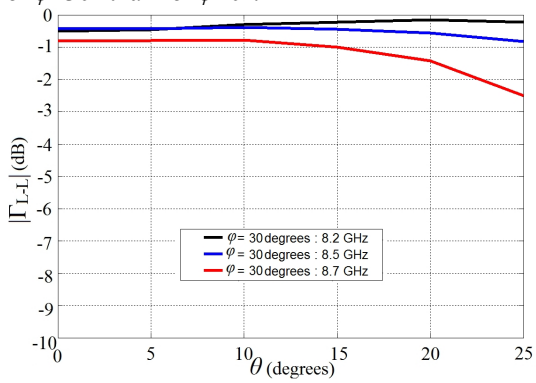


Fig. 4. Simulated magnitude of the reflection coefficient in LHCP for various incidence angles θ (in the φ=30° plane) at three frequency points.

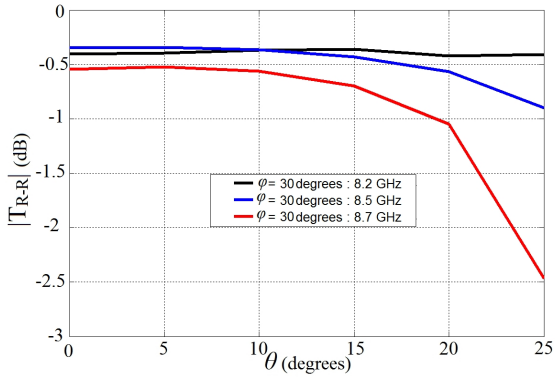


Fig. 5. Simulated magnitude of the transmission coefficient in RHCP for various incidence angles θ (in the φ=30° plane) at three frequency points.

Fig. 6 shows that, even in a quite critical configuration (θ=20° and φ=0°), the phase difference between two consecutives states is preserved over a large frequency bandwidth (between 8.2 GHz and 8.5 GHz). It is recalled that the unit-cell provides four states, as described in [8]. To achieve four phase states with a 90° phase-shift between two adjacent states, the rotation angle of the resonant wire has been optimised. It must be highlighted that better performance is obtained for lower frequencies. This is obvious from Fig. 2 to 5 where the best results are obtained at 8.2 GHz. It is important to note that the unit-cell had been optimised under normal incidence. This suggests that the center frequency has been shifted downwards and that a further optimisation (possibly using the height of the metallic grid) would be possible.

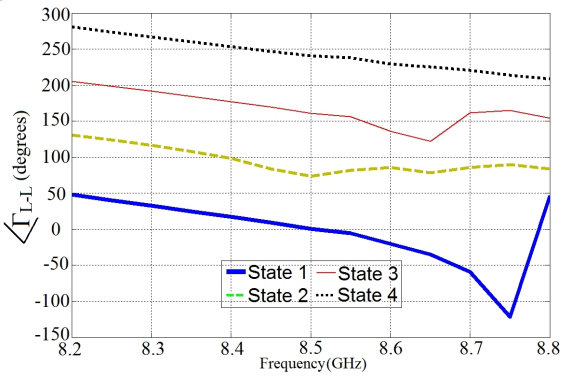


Fig. 6. Simulated phase of the LHCP reflection coefficient according to frequency for the four phase states of the unit-cell; angle θ=20° (for φ=0°).

III. Reduction of the Number of Phase Control

In the previous version of the unit-cell (Fig. 1b), 16 switching elements were necessary to reconfigure the phase response of the unit-cell (2 switches per horizontal segment on each cell side): this makes it very complex to be controlled. An improved version with only 8 switching elements is introduced here (Fig. 7). To facilitate the comparison, Fig. 1b and Fig. 7 represent the topology of both cells for the same phase state. In Fig. 7, only one switch is used instead of two to disconnect the horizontal segments from the vertical one. The general shape of the activated resonant wire and the transparency of each parasitic segment have been optimised (width, central pin, gap between active and parasitic wire, etc.). Figs. 8 to 10 show the three others configurations (State 2 to 4, respectively) of the improved version of the unit-cell (in comparison to the previous version described in [8]). The simulated performance of the four possible phase states in LHCP reflection is represented Fig. 11. The LHCP incident wave is reflected with a reflection loss better than 1 dB over a 0.4-GHz range (4.7%). The reflection phase responses in LHCP are plotted in Fig. 11b between 8.2 and 8.6 GHz; four 90°-spaced phase configurations are obtained with almost the same frequency dispersion. At the same time, as described in Fig. 12a, the RHCP incident wave is transmitted through the CPSS with insertion loss lower than 1 dB over a 0.4-GHz range (4.7%). Fig. 12b shows that the RHCP incident wave is transmitted with a nearly constant phase whatever the activated resonance wire. The equivalent bit number, defined in [8], is used to assess the overall unit-cell performances by taking into account the gap between all phase states. The corresponding equivalent bit number of the improved unit-cell represented in Fig. 13 is around 1.95 bits.

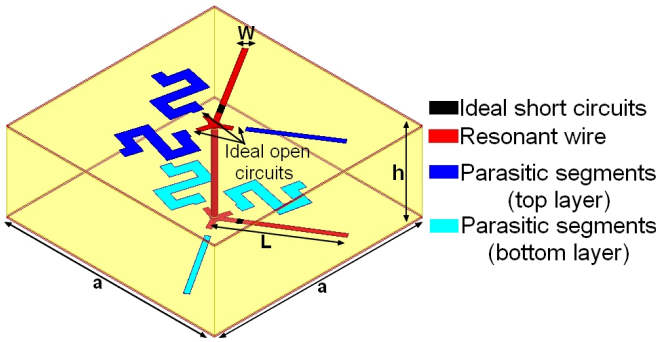


Fig. 7. Improved unit-cell in the same phase state (State 1) as in Fig. 1b: a=22.88mm, w=0.5mm, h=8.09mm, L=10.6mm.

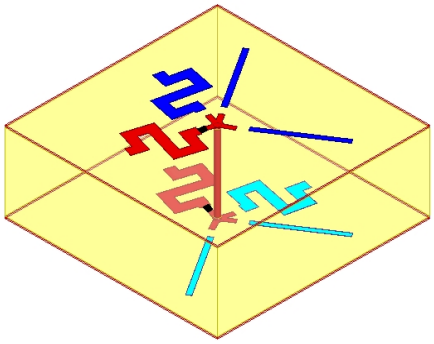


Fig. 8. Improved unit-cell in State 2.

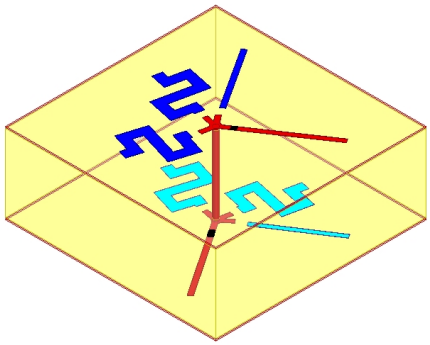


Fig. 9. Improved unit-cell in State 3.

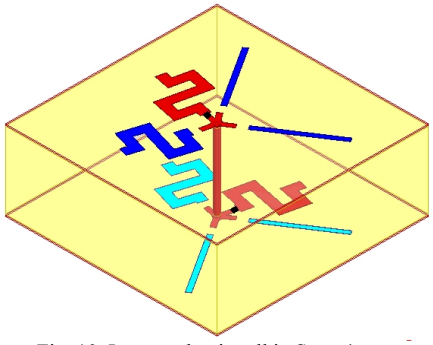
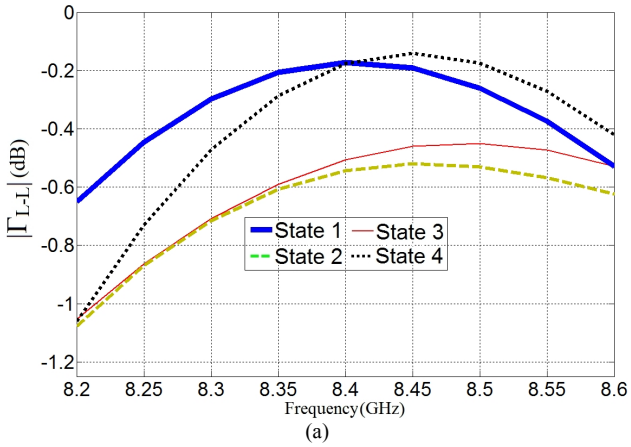
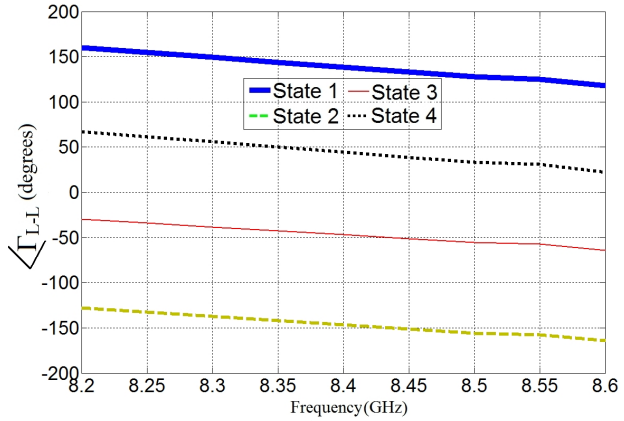


Fig. 10. Improved unit-cell in State 4.

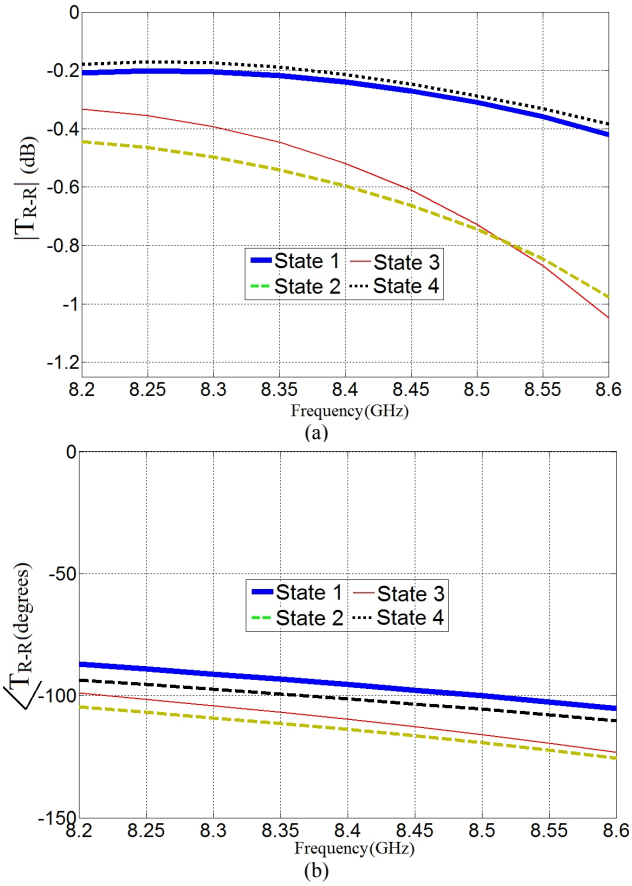


(a)



(b)

Fig. 11. Simulated reflection coefficients of the four states for a LHCP incident wave. (a) Magnitude. (b) Phase.



(b)

Fig. 12. Simulated transmission coefficients of the four states for a RHCP incident wave. (a) Magnitude. (b) Phase.

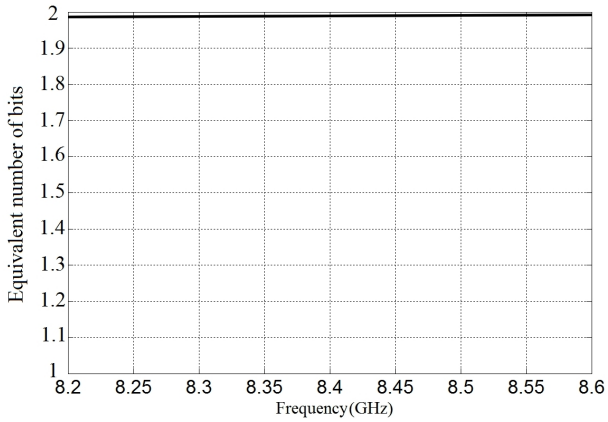


Fig. 13. Simulated equivalent number of bits for a LHCP incident wave.

To conclude, an improved version of the CPSS unit-cell with only 8 switching elements (instead of 16 in the previous version) is proposed to reconfigure the phase response of the unit-cell. In comparison to the previous version of the unit-cell, the bandwidth is lower (0.4 GHz instead of 0.55 GHz) but this new configuration lead to an easier implementation and to a positive impact on the loss.

IV. Conclusion

The characteristics of a CPSS unit-cell for dual-polarised CP reflectarrays have been studied under oblique incidence. Our results show that this cell can be used up to 15° with no further optimization. Moreover, an improved design of the CPSS unit-cell has been proposed. This new configuration allows reducing the total number of phase controls by a factor two. Its reflection and insertion loss is lower than 1 dB over the [8.2-8.6] GHz range. A positive impact is expected on both performance (reduced loss) and ease of implementation (simpler routing of biasing lines).

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