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Antenna-Filter-Antenna-Based Cell for Linear–to–Circular Polarizer Transmit-Array

Parinaz Naseri, Carlos A. Fernandes
Instituto de Telecomunicações, IST
Universidade de Lisboa
Lisbon, Portugal
parinaz.naseri@lx.it.pt

Sérgio A. Matos, Jorge R. Costa
Instituto de Telecomunicações, IST
Instituto Universitário de Lisboa, (ISCTE-IUL)
Lisbon, Portugal

***Abstract*—In this paper, we propose a dual-band linear–to–circular polarization converter element based on the antenna–filter–antenna (AFA) structure. The traits of this cell include thin three-layer structure and ability to convert a linear incident wave to two orthogonal circular polarizations at two non-adjacent frequency bands. This combination of physical and electrical specifications makes this cell a novel solution. An example of this cell suitable for satellite communication is designed to operate at 20GHz and 30GHz (satellite Ka-band) with 4% and 8% bandwidth, respectively.**

Keywords—dual-band; polarizer; polarization converter; frequency selective surface; antenna-filter-antenna.

I. INTRODUCTION

In some satellite and point-to-point communications, circular polarization (CP) is a more desirable choice due to its advantages over linearly polarized radiation. The polarization efficiency and propagation link budget in these applications can be improved by exploiting the fact that circularly polarized wave is less influenced by multipath fading, Faraday rotation effect, and the orientation of the receiving antenna. Conventional CP solutions include microstrip patch, wire, helix, spiral, and horn antennas [1].

In certain applications, besides radiating CP, the antenna is required to operate at two distinct and non-adjacent frequency bands. For instance, in Ka-band satellite communication, the downlink occurs at 20GHz and the uplink occurs at 30GHz for the sake of communication reliability and efficiency. Moreover, there is an added requirement in multi-cell Ka-band satellite communication in which if the ground terminal receives a left handed circularly polarized (LHCP) wave at 20GHz, it should transmit right handed circularly polarized (RHCP) wave at 30GHz.

Traditionally, the ground terminal antenna for Ka-band satellite communications is either composed by the assembly of a horn antenna and orthomode transducer to feed a reflector [2] or a transmit-array [3] or either a phased array of dual-band dual-CP patch antennas like in [4]. However, these solutions are either bulky and expensive or compact but inefficient and hard to fabricate at Ka-band frequencies.

In this communication, we introduce a three-layer antenna–filter–antenna (AFA) element to be used in a dual-band linear-to-circular polarization converter with opposite polarizations in each band. A finite array of this element can be put before a simple dual-band linear polarized source antenna and feed a large aperture (i.e. a reflector or a lens) with dual-circular polarization at two frequency bands. By doing so, the design and fabrication complexities of a dual-band dual-circularly polarized feed antenna can be broken down. At first, this polarizer cell operates like other standard polarization converters and divides a linearly polarized wave into two orthogonal components [5]. But after this step, the polarizer generates +90° phase shift between them at lower frequency band and –90° phase shift at the higher band of operation.

II. ANTENNA-FILTER-ANTENNA ELEMENT

An FSS element, in order to function as a linear-to-circular polarizer, should behave differently for the two orthogonal components of a linearly-polarized incident wave. It should transmit both components with maximum and equal magnitudes and 90° phase difference [5]. Here, we employed a non-symmetric AFA element regarding x and y axis. The structure of the proposed element is depicted in Fig. 1. The dimensions of the elements are mentioned in Table I. The dielectric substrates are 0.508mm-thick Rogers RT5880 ($\varepsilon_r = 2.2,\ tan\delta = 0.0009$). Therefore, the whole thickness of the structure is only 1.067mm which is equal to $0.07\lambda_{20GHz}$ and $0.11\lambda_{30GHz}$.

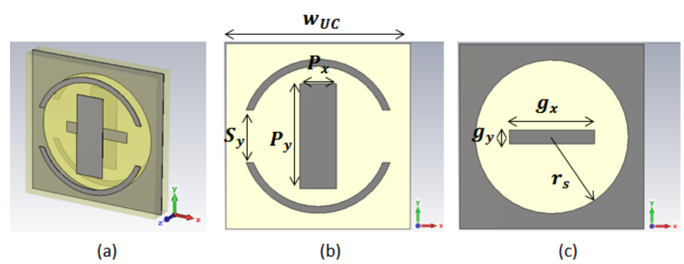

Fig. 1. Structure of the AFA element: (a) 3D view, (b) first layer, and (c) second layer.

Table I. AFA UNIT-CELL DIMENSIONS

parameter	length (mm)	parameter	length (mm)
w_{UC}	5.3	r_s	2.2
S_y	1.5	P_x	1.05
P_y	3	g_x	2.45
g_y	0.4		

Conventionally FSS-based polarizers are designed by stacking FSS layers with thick $(0.2\lambda_0 - 0.3\lambda_0)$ dielectric slabs as a chain of resonators and impedance invertors [5]. Not only may these solutions lead to thick and bulky solutions, they also offer synthesis of limited category of filters. AFA elements, on the other hand, are composed of three layers of resonators that can form more general filters [6]. To the best of the authors' knowledge, the cell proposed in this communication is a novel very compact solution which converts a linear polarization to two orthogonal circular polarizations at two distinctive frequency bands.

Here, we employed a similar structure to the one proposed in [7] to design an element with the reflection coefficients presented in Fig. 2. In [7], unlike the requirement for a linear-to-circular polarizer, the cell generates 180° phase difference between the two orthogonal linear components of a wave at X and K-bands for a different application. All the unit-cell (UC) simulations are done with CST Studio Software using periodic boundary conditions. Therefore, the UCs are simulated in infinite FSS array. Fig. 3 presents the magnitude and phase of the transmission coefficients of the AFA UC in response to TE and TM normal incident waves.

By comparison between Fig. 2 and Fig. 3, it is noticeable that the phase difference between the two frequency responses starts when the UC presents the first resonance for TE incident wave at 18GHz but not for the TM incident wave. Thusly, we can see the 90° phase difference between the transmission responses in responses in Fig. 3 at both 20GHz and 30GHz.

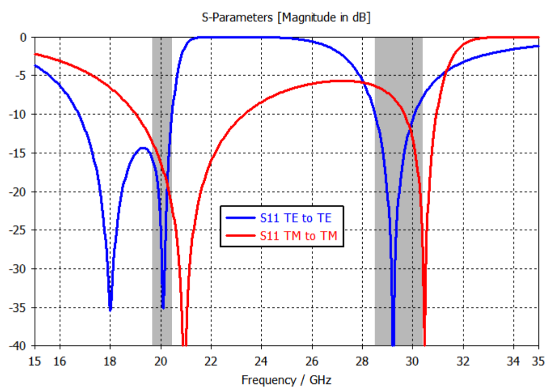

Fig. 2. Reflection coefficients of the AFA UC in response to TE and TM incident waves.

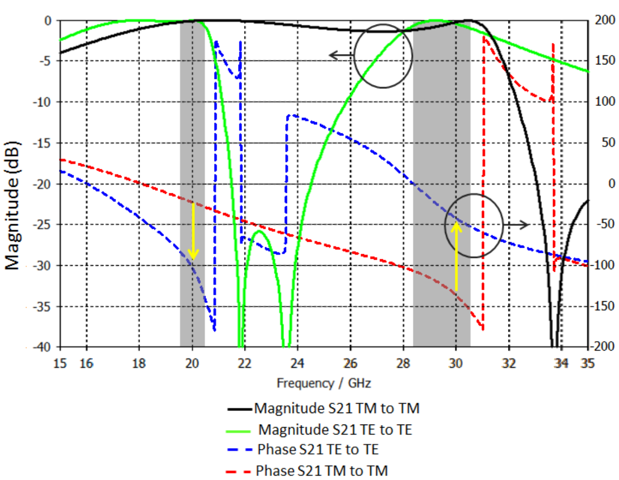

Fig. 3. Magnitude and phase of transmission coefficients of the AFA cell to TE and TM incident waves.

However, the interesting trait of this design is that while the transmission response of the UC to the TE wave is leading 90° comparing to the UC's response to the TM wave at 20GHz, it is lagging 90° at 30GHz. It means that the 45°-rotated AFA cell converts y-polarization to an RHCP wave at 20GHz and an LHCP wave at 30GHz. This is confirmed in Fig. 4. Moreover, it is noticeable that this polarizer UC operates at 20GHz and 30GHz with transmission loss of 0.1dB and 0.4dB respectively. Moreover, the fractional bandwidths of the cell (corresponding to the shade regions in Figs. 2 to 4), where the cross polarization is more than 15dB and the reflection is less than 10dB, are about 4% (800MHz) and 8% (2.3GHz). This bandwidth is adequate for Ka-band satellite communication.

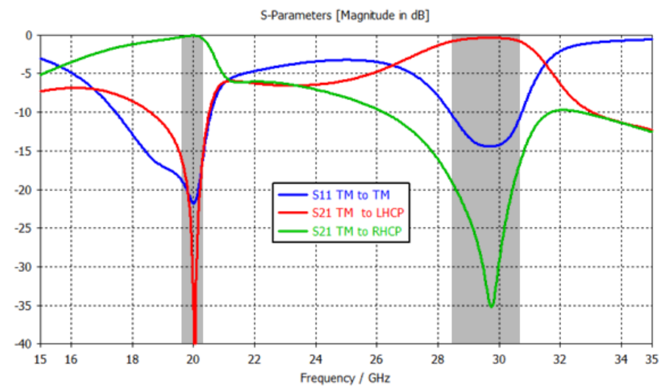

Fig. 4 The reflection and transmission coefficients of the polarizer UC simulated with periodic boundary condition.

III. Conclusion

In this paper, we proposed a dual-band low-profile antenna-filter-antenna based polarizer unit-cell that can operate at 20GHz and 30GHz. It converts a y-directed linearly-polarized incident wave to an RHCP wave at the lower band and an LHCP wave at the upper band.

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