A Dielectric Linear-to-Circular Polarization Converter Exploiting Uniaxial Anisotropy

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***Abstract*—A linear-to-circular polarization converter, consisting of a suitable arrangement of thin periodic air-dielectric slabs, is presented. The uniaxial nature of the periodic structure, highlighted by the field propagation matrix representation, is exploited to perform the required field polarization conversion. The performances of the proposed polarizer are illustrated by analyzing the radiative performance in terms of impedance bandwidth, axial ratio and realized gain of a horn and a wideband planar slot lens antenna.**

Keywords—Polarization Converter, Periodic Structures, Uniaxial anisotropy.

I. INTRODUCTION

High performance antennas are currently used in the latest avionics, maritime or satellite applications [1]. Such systems generally take advantage of circularly polarized field to limit signal fading caused by changes in the orientation of the receiving/transmitting antenna, by atmospheric conditions or multipath losses. To limit these drawbacks, making the radio system more compact and performing, suitable dielectric lenses useful to significantly increase the antenna gain can be used.

A novel approach to design lightweight dielectric lenses, useful for reducing the weight of radiating systems operating in the lower end of the microwave band, was recently proposed [2]-[3]. This approach makes use of a set of thin dielectric disks stacked along the optical axis of the lightweight lens so to mimic the electromagnetic behavior of the corresponding benchmark massive dielectric lens. This not only allows to reduce complexity and manufacturing costs, but also to include suitable disk metallization's so modifying the lens outgoing field polarization state [4].

The radiative performances of a horn antenna equipped with two dielectric lenses each having different polarization conversion capabilities were investigated in [4]. In particular, the first lens was employed in a horn antenna for converting a vertical linear polarized wave into a linear slant-45°, while the second lens was employed in the same antenna to realize a linear-to-circular polarization conversion [4]. In both cases a high values of the cross-polarization rejection ratio as well as significant increase in the horn antenna realized gains introduced by the thin stacked disk dielectric lenses were observed.

In this contribution, taking advantage of field propagation in thin periodic air-dielectric slabs, a pyramidal horn and a broadband slot antenna equipped with a polarization converter and with a lens integrating a linear-to-circular polarization conversion capability, respectively, are presented.

II. POLARIZATION CONVERTER MODEL

The periodic arrangement of thin layered dielectric slabs forming the polarization converter is modeled by the following equivalent dielectric permittivity tensor

$$\underline{\boldsymbol{\epsilon}} = \epsilon_t \mathbf{1}_t + \epsilon_n \hat{\boldsymbol{n}}\hat{\boldsymbol{n}}. \qquad (1)$$

where $\mathbf{1}_t$ is the transverse unitary dyad, while ϵ_t and ϵ_n are the relative transverse and longitudinal component of the equivalent permittivity tensor with respect to the normal layered plane (n-axis), respectively. Using the propagation and transmission matrix, as well as the *Floquet* boundary conditions of the periodic structure, it is possible to derive, after several analytical manipulations (not reported here for the sake of brevity), the expression of the electrodynamic tensor components appearing in (1), whose quasi-static terms [5] take the following form:

$$\begin{cases} \epsilon_t = \dfrac{t_1\,\epsilon_1 + t_2\,\epsilon_2}{t_1 + t_2} \\ \epsilon_n = \dfrac{\epsilon_1 \epsilon_2 (t_1 + t_2)}{t_2\,\epsilon_1 + t_1\,\epsilon_2} \end{cases} \qquad (2)$$

where ϵ_1 and ϵ_2 are the relative permittivities, t_1 and t_2 are the thicknesses of the slabs forming the layered structure. Few elementary cells allow to obtain an electromagnetic behavior similar to that of an infinite periodic structure.

The polarization conversion of a plane wave from linear to circular can be achieved by exploiting the different phase velocities of the ordinary and extraordinary wave experienced by the field propagating in a uniaxial material. Circular polarization is achieved when the amplitude of the two waves has the same amplitude at the input and a phase delay of 90° at the converter output. This occurs when the length s of the polarization converter satisfies the relation

$$s = \frac{\lambda_0}{4} \frac{1}{\left| \sqrt{\varepsilon_n} - \sqrt{\varepsilon_t} \right|} \qquad (3)$$

where λ_0 being the free-space wavelength.

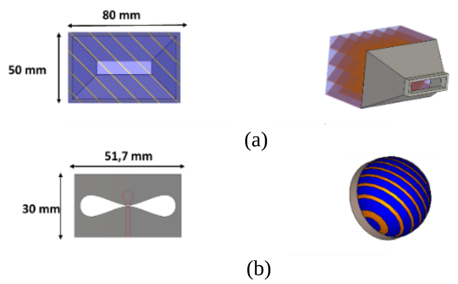

Figure 1. Pyramidal horn antenna equipped with polarization converter (a); (b) wideband planar slot-lens antenna equipped with of a spherical meniscus having periodic vertical notches. Blue: air, orange: dielectric slab.

III. Polarization Converter Radiating Performances

The horn and slot antenna equipped with the polarization converter and with lens (consisting of a spherical meniscus with air periodic vertical notches) integrating a linear-to-circular polarization conversion capability, respectively, are shown in Fig. 1. A broadband radiating slot similar to the one proposed in [6] is used to excite the polarization converter. Equations (2) and (3) were used for the preliminary sizing of the converter, while a full-wave simulation (Finite Integration Technique), based on periodic *Floquet* boundary conditions, to predict the behavior of the axial ratio from the converter output in the frequency range 2.5-7 GHz (see Fig. 2), was implemented. Doing so, an axial ratio fractional bandwidth (ARFBW) of 36.9% was achieved. Starting from this result, the antennas shown in Fig. 1 were analyzed using the same dimensions for converter and lens. The performed numerical investigations have shown that, while for the horn antenna equipped with the polarizer converter these equations can be used without any optimization, for the slot antenna (realized with Rogers 4003C substrate) equipped with a lens it is necessary to resort to a subsequent optimization of the slab thicknesses and the lens radius since the field to the lens input is more irregular. Furthermore, the lens antenna requires the additional use of a dielectric spacer ($\epsilon_r = 3.38$, thickness = 10 mm) between the slot and lens to increase the axial ratio bandwidth [7]. After optimization, the electrical and geometric dimensions of the converter and the lens used to excite the circular polarization at 5 GHz reported in Table I, were obtained.

In Fig. 3 the frequency behavior of the reflection coefficients and of the axial ratio for both considered antennas are reported. The figure shows an ARFBW=53.2% for the horn antenna and 54.2% for the slot antenna. Finally, for the sake of brevity, only the radiation diagrams of the horn antenna equipped with the polarization converter are reported in Fig. 4.

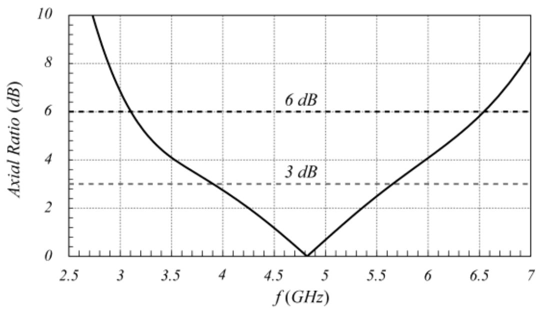

Figure 2. Frequency behavior of the axial ratio along the optical axis obtained from the electromagnetic analysis of the unit cell.

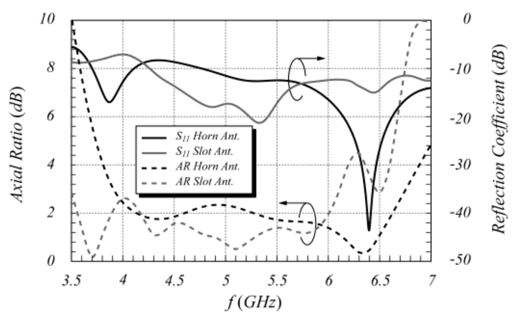

Figure 3. Frequency behavior of the axial ratio along the boresight axis for the horn and slot-lens antenna.

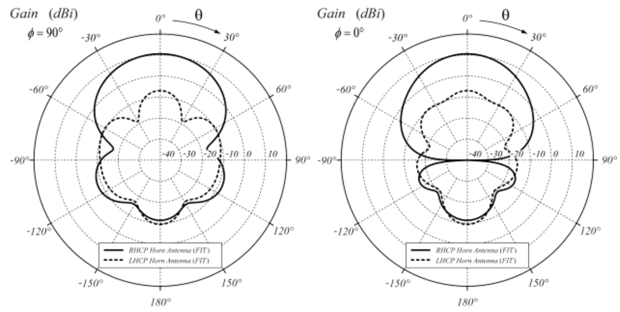

Figure 4. Radiation diagram of the horn antenna with polarization converter at 5 GHz. Left *E*-plane, right *H*-plane.

TABLE I
ELECTRICAL AND GEOMETRICAL PARAMETERS

	ϵ_1	ϵ_2	$t_1(mm)$	$t_2(mm)$	$s\ (mm)$
Horn Ant.	12.2	1	0.762	9	44.6
Slot Ant.	12.2	1	2	5	30.0

IV. Conclusions

The electromagnetic performance of a novel dielectric linear-to-circular polarizer based on the uniaxial anisotropic properties induced by a periodic dielectric layered medium has been presented. Electrodynamic and quasi-static components of the uniaxial equivalent permittivity tensor have been determined and suitable polarization converter design guidelines (not reported for the sake of brevity) have been derived. A horn antenna and a broadband printed slot antenna equipped with a lens integrating the proposed polarizer showed good performances in terms of gain, impedance and axial ratio bandwidth. To accurately model the field propagation and diffraction effects taking place in the antennas, as well as between the different disks forming the polarizer, full-wave simulations have been employed. The numerical investigations showed the suitability of the proposed polarization converters in ensuring excellent performance without requiring the use of dedicated networks thus reducing the cost and complexity of the overall antenna system.

References

[1] B. G. Evans, *Satellite Communication Systems*, 3rd ed. London, U.K.: The Institution of Engineering and Technology, 2008.

[2] R. Cicchetti, V. Cicchetti, A. Faraone, and O. Testa, "A class of lightweight spherical-axicon dielectric lenses for high gain wideband antennas," *IEEE Access*, vol. 9, pp. 151873–151887, Oct. 2021.

[3] E. Baldazzi, R. Cicchetti, O. Testa, and L. Foged, "Performance of a class of stacked-disk dielectric lenses for lightweight antennas," AP-S/URSI, Portland, Oregon, USA, July 23–28, 2023.

[4] E. Baldazzi, R. Cicchetti, O. Testa, and L. Foged, "A novel dielectric lens with integrated polarization conversion capability," *CAMA*, Genoa, Italy, Nov. 15–17, 2023.

[5] S. M. Rytov, "Electromagnetic properties of a finely stratified medium," *Soviet Physics* JEPT, vol. 2, no. 3, pp. 466-475, May 1956.

[6] R. Cicchetti, V. Cicchetti, A. Faraone, L. Foged, and O. Testa, "A wideband high-gain dielectric horn-lens antenna for wireless communications and UWB applications," *IEEE Trans. Antennas Propag.*, vol. 71, no. 2, pp. 1304–1318, Feb. 2023.

[7] Z. -X. Xia and T. Sheng, "3-D-printed wideband circularly polarized dielectric lens antenna with integrated dielectric resonator antenna feed," 2022 *IEEE MTT-S* IMWS-AMP, Guangzhou, China, 2022, pp. 1-2, Nov. 2022.