13th International Congress on Artificial Materials for Novel Wave Phenomena – Metamaterials 2019
Rome, Italy, Sept. 16th – Sept. 21st, 2019

Design of WideBand Transmission Polarization Converters

F. Costa [1], **M. Borgese** [2]

[1] University of Pisa, Department of Information Engineering, Via Caruso 16, 56122, Pisa, Italy
[2] GreenWaves s.r.l., Milan, Italy
filippo.costa@unipi.it

***Abstract* – A designing tool for wideband transmission polarization converting surfaces is presented. The optimized wideband polarizer comprises several metasurface layers whose unit cell is gradually rotated. The analysis is based on an analytical transmission line model of the multilayer structure with anisotropic elements.**

I. INTRODUCTION

The ability to manipulate the polarization [1] state of optical waves is useful in a wide range of applications spanning from microwave to optics. Popular applications are related to communications and antennas, remote environmental monitoring, to realize optical instrumentation or microwave devices such as circulators and isolators. The manipulation of optical waves polarization state is based on the use of bulky waveplates, which are made of birefringent materials composed of crystalline solids and liquid crystals. However, the inherent disadvantages in terms of size, collimation, and bandwidth of these configurations prevent the miniaturization and integration of optical systems. Metasurfaces have been reported to provide a very effective approach to manipulate several basic properties of electromagnetic waves (amplitude, phase and polarization) and consequently, they are a promising pathway towards an efficient polarization conversion via ultrathin, miniaturized, and easily integrable designs.

High-performance metamaterial-based linear polarization converters have been realized for both transmission and reflection modes in the gigahertz, terahertz, infrared, and optical frequency regimes [1]–[4]. Reflection mode polarization converter [5], [6] are easier to design with respect to transmission ones since the amplitude control is guaranteed by the presence of a ground plane, that is, the ground plane guarantee a unitary reflection coefficient for both polarization components. Only the phase profiles of the two-components of the impinging wave needs to be adequately controlled. Conversely, in transmission mode [7] polarization converters, the simultaneous control of both amplitude and phase is required.. By using a single layer metasurface, the amplitude and phase control can be achieved at a single frequency or in a narrow frequency band. On the other hand, broadband circular polarization conversions are obtained with 3D optical metamaterials [8], [9]. Therefore, these polarizer configurations require highly advanced fabrication techniques, leading to a difficult implementation of such designs in integrated metasurface-based photonics systems. Some polarization converters based on Frequency Selective Surfaces (FSS) and metasurfaces [7], [10] have been proposed in the literature but they are customized designs typically based on the experience of the designer. The idea of this work is to present a general designing tool based on an analytical transmission line model able to compute the transmission and reflection response of multilayer metasurfaces comprising anisotropic elements. The optimized designs are obtained by controlling the rotation factor of every layer of the polarization and the distance among them but keeping unmodified the geometry of the unit cell layer by layer.

II. ANALYSIS APPROACH

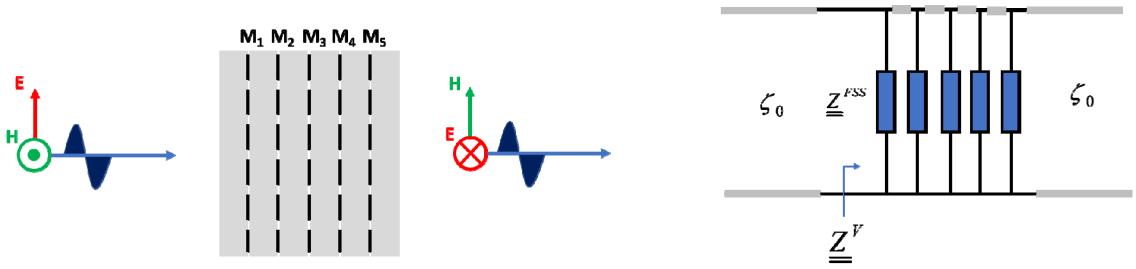
The analysis of the cascaded anisotropic surfaces is carried out by resorting to a transmission line model in which the metasurface is represented by a shunt impedance. Fig. 1 reports a 2D layout of the multilayer structure and its equivalent circuit model. In the design of polarization surfaces, the metasurface impedances must be treated as a matrix since the metasurface response is polarization dependent [11], [12]. The full impedance matrix of the FSS element as a function of frequency is derived from a full-wave simulation for a specific azimuth angle [11], [13]. Once computed the impedance matrix of the element, the reflection and transmission coefficients of a multilayer structure comprising dielectric layers and generically rotated FSS elements can be computed according to transfer matrix (ABCD) approach [7]. The full scattering matrix, both for both TE and TM polarization, can be derived as:

$$\begin{pmatrix} \overline{\overline{S}}{}_{11}^{TE/TM} & \overline{\overline{S}}{}_{21}^{TE/TM} \\ S_{12}^{TE/TM} & S_{22}^{TE/TM} \end{pmatrix} = \begin{pmatrix} -\overline{\overline{I}} & \dfrac{\overline{\overline{Bn}}}{\varsigma_0^{TE/TM}} + \overline{\overline{A}} \\ \dfrac{\overline{\overline{n}}}{\varsigma_0^{TE/TM}} & \dfrac{\overline{\overline{Dn}}}{\varsigma_0^{TE/TM}} + \overline{\overline{C}} \end{pmatrix}^{-1} \begin{pmatrix} \overline{\overline{I}} & \dfrac{\overline{\overline{B}}\,\overline{\overline{n}}}{\varsigma_0^{TE/TM}} - \overline{\overline{A}} \\ \dfrac{\overline{\overline{n}}}{\varsigma_0^{TE/TM}} & \dfrac{\overline{\overline{D}}\,\overline{\overline{n}}}{\varsigma_0^{TE/TM}} - \overline{\overline{C}} \end{pmatrix} \tag{1}$$

The terms of the ABCD matrix of the cascade system comprising metasurface layers and a dielectric in between are computed as follow:

$$\begin{pmatrix} \overline{\overline{\mathrm{A}}} & \overline{\overline{B}} \\ \overline{\overline{C}} & \overline{\overline{D}} \end{pmatrix} = \begin{pmatrix} \overline{\overline{I}} & \overline{\overline{0}} \\ \overline{\overline{\mathrm{n}}}\,\overline{\overline{\mathrm{Y}}}_{\mathrm{s1}} & \overline{\overline{I}} \end{pmatrix} \begin{pmatrix} \cos(kd_1)\overline{\overline{\mathrm{I}}} & \text{-j}\sin(kd_1)\varsigma_1^{TE/TM}\overline{\overline{\mathrm{n}}} \\ \text{-j}\dfrac{\sin(kd_1)}{\varsigma_1^{TE/TM}}\overline{\overline{\mathrm{n}}} & \cos(kd_1)\overline{\overline{\mathrm{I}}} \end{pmatrix} \begin{pmatrix} \overline{\overline{I}} & \overline{\overline{0}} \\ \overline{\overline{\mathrm{n}}}\,\overline{\overline{\mathrm{Y}}}_{\mathrm{s2}} & \overline{\overline{I}} \end{pmatrix} \tag{2}$$

The impedance of the metasurface relates the tangential components of the electric and magnetic fields and it is represented by a tensor. If additional metasurface and dielectric layers are employed, relation (2) can be applied recursively. The ABCD formulation can be adopted also for computing the oblique incidence behavior but we have to remind that we have implicitly assumed that no angular variation (elevation angle) of the metasurface impedance is considered by the model. On the contrary, the spatially dispersive effects of the spacers are taken into account. An important rule of thumb in considering the application of the transmission line model is the distance among the metasurface layers. In order to avoid the effects of high order Floquet modes, the distance between metasurface layers has to be maintained above D/3 where D is the FSS periodicity [14].

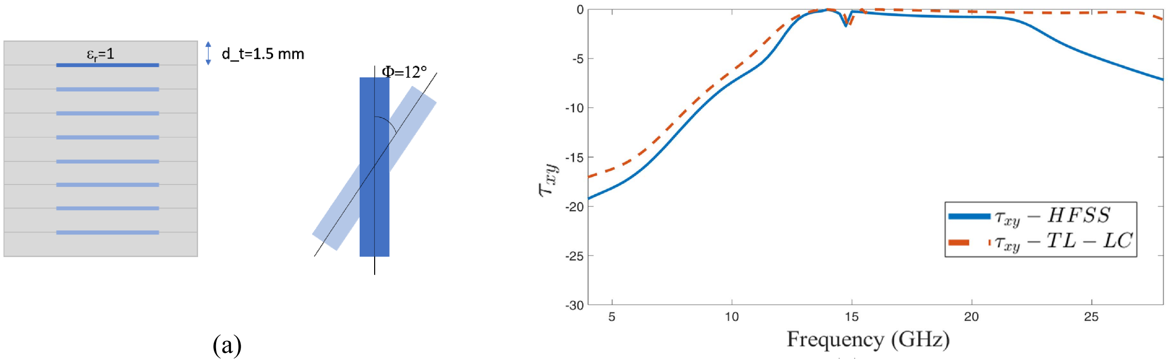


(a) (b)

Fig. 1 - (a) 2D layout of the multilayer structure and (b) equivalent circuit model.

III. POLARIZATION CONVERTING SURFACES

The purpose of this work is to design a transmission wideband polarization converting surfaces. The design strategy is based on a of multiple metasurface layers comprising anisotropic unit cell. The anisotropic element selected in this case is a dipole element and it is partially and gradually rotated layer by layer. The degrees of freedom involved in the design are the number of layers, the relative degree of rotation and the spacing between layers. The optimization of the structure is carried out through the transmission line model described in the previous section. The TL model, differently from an optimization procedure based on a full-wave simulation, allows a very rapid optimization of the multilayer structure. As an example, an optimized 8-layers polarization converting surface comprising partially rotated dipole elements is shown in Fig.2. The figure reports the comparison of the cross-polar transmission coefficient obtained by using HFSS and the transmission line model. The dipoles are gradually rotated by an angle of 18° and are spaced of 1.5 mm.



(a)

Fig. 2 - (a) Stack-up of the wideband polarization converting surface with the rotated dipoles unit cell. (b) cross-polarized transmission after the multilayer polarizing surface.

VI. CONCLUSION

The paper presented a general methodology for designing transmission type wideband polarization converters. The design strategy is based on an efficient transmission line analysis of the multilayer structure formed by anisotropic unit cells which are gradually rotated layer by layer. The optimization involves three or four degrees of freedom and thus the tool can be adopted to design other polarization converting surfaces with different bandwidth properties.

REFERENCES

[1] L. Li, Y. Li, Z. Wu, F. Huo, Y. Zhang, e C. Zhao, «Novel Polarization-Reconfigurable Converter Based on Multilayer Frequency-Selective Surfaces», *Proc. IEEE*, vol. 103, n. 7, pagg. 1057–1070, lug. 2015.
[2] W. Liu *et al.*, «Realization of broadband cross-polarization conversion in transmission mode in the terahertz region using a single-layer metasurface», *Opt. Lett.*, vol. 40, n. 13, pagg. 3185–3188, lug. 2015.
[3] X. Zhu *et al.*, «Design of a Bandwidth-Enhanced Polarization Rotating Frequency Selective Surface», *IEEE Trans. Antennas Propag.*, vol. 62, n. 2, pagg. 940–944, feb. 2014.
[4] M. Euler, V. Fusco, R. Cahill, e R. Dickie, «325 GHz Single Layer Sub-Millimeter Wave FSS Based Split Slot Ring Linear to Circular Polarization Convertor», *IEEE Trans. Antennas Propag.*, vol. 58, n. 7, pagg. 2457–2459, lug. 2010.
[5] E. Doumanis, G. Goussetis, J. L. Gomez-Tornero, R. Cahill, e V. Fusco, «Anisotropic Impedance Surfaces for Linear to Circular Polarization Conversion», *IEEE Trans. Antennas Propag.*, vol. 60, n. 1, pagg. 212–219, gen. 2012.
[6] M. Borgese, F. Costa, S. Genovesi, A. Monorchio, e G. Manara, «Optimal Design of Miniaturized Reflecting Metasurfaces for Ultra - Wideband and Angularly Stable Polarization Conversion», *Sci. Rep.*, vol. 8, n. 1, pag. 7651, mag. 2018.
[7] C. Pfeiffer e A. Grbic, «Bianisotropic Metasurfaces for Optimal Polarization Control: Analysis and Synthesis», *Phys. Rev. Appl.*, vol. 2, n. 4, pag. 044011, ott. 2014.
[8] G. A. Morin, «A Circular Polarization Selective Surface Made of Resonant Helices», DEFENCE RESEARCH ESTABLISHMENT OTTAWA (ONTARIO), DREO-1269, nov. 1995.
[9] J.-G. Yun *et al.*, «Broadband ultrathin circular polarizer at visible and near-infrared wavelengths using a non-resonant characteristic in helically stacked nano-gratings», *Opt. Express*, vol. 25, n. 13, pagg. 14260–14269, giu. 2017.
[10] S. M. A. Momeni Hasan Abadi e N. Behdad, «A broadband, circular-polarization selective surface», *J. Appl. Phys.*, vol. 119, n. 24, pag. 244901, giu. 2016.
[11] A. M. Patel e A. Grbic, «Transformation Electromagnetics Devices Based on Printed-Circuit Tensor Impedance Surfaces», *IEEE Trans. Microw. Theory Tech.*, vol. 62, n. 5, pagg. 1102–1111, mag. 2014.
[12] M. Selvanayagam e G. V. Eleftheriades, «Design And Measurement of Tensor Impedance Transmitarrays For Chiral Polarization Control», *IEEE Trans. Microw. Theory Tech.*, vol. 64, n. 2, pagg. 414–428, feb. 2016.
[13] G. Minatti, S. Maci, P. D. Vita, A. Freni, e M. Sabbadini, «A Circularly-Polarized Isoflux Antenna Based on Anisotropic Metasurface», *IEEE Trans. Antennas Propag.*, vol. 60, n. 11, pagg. 4998–5009, nov. 2012.
[14] F. Costa, A. Monorchio, e G. Manara, «Efficient Analysis of Frequency-Selective Surfaces by a Simple Equivalent-Circuit Model», *IEEE Antennas Propag. Mag.*, vol. 54, n. 4, pagg. 35–48, ago. 2012.