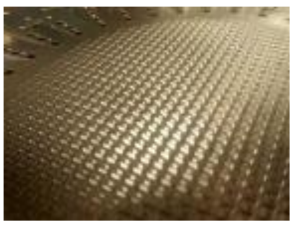
Higher-symmetric periodic structures for graded-index lenses and EBGs

Abstract

Artificial materials have been widely studied and used in photonics and microwaves in the last decades. Recently, researches discovered that the introduction of specific higher symmetries in each cell of a periodic medium [1] is an effective approach to obtain unprecedented exotic behaviour [2],[3] and overcome current limitations of these devices. Simple symmetries of purely spatial type (glide or twist transformations) can have huge impact on the properties of the resulting materials, thus defining wideband behaviours [4]-[6] for flat lenses or large stop bands for novel EBG materials [7]-[9].
The interest in these applications is proved by the involvement of several research groups and companies with very different background. This short course will propose a theoretical introduction about propagation of waves along glide surfaces and twist lines, including novel modelling methods for these structures. A thorough overview of the applications for antennas and microwave component together with simple rules for their design will be given during the course.

Graphical abstract




Recommended prerequisites

Antennas and propagation theory:
plane waves, modes in waveguides, the meaning of frequency dispersion and the definition of phase and group velocity, aperture antennas, scattering and transmission matrix formalism, basic properties of metamaterials or periodic structures.

Learning objectives

- Recognize a higher-symmetric structure, predict its dispersive behaviour, and compare it to the one of a periodic structure without higher symmetry,
- Perform a simulation with commercial software in order to obtain the dispersive behaviour of a higher-symmetric structure [10]-[12],
- Have a basic knowledge on how to formulate a dispersive problem in a higher-symmetric structure and how to solve it (e.g., with a mode-matching formulation or with equivalent circuit models) [13],
- Know how to use higher-symmetric structure to design artificial flat lenses (e.g., Luneburg lens) operating on a wide band of frequency [4]-[6],
- Design an Electromagnetic Band-gap (EBG) material by using higher-symmetric unit cells of periodicity [7]-[9],
- Achieve anisotropic responses by means of cells having suitable geometry (useful e.g. for transformation optics).

Course Outline

1. Definition of higher-symmetric structures. Spatial and spectral properties. (30 minutes)
   The definition of higher symmetric structure will be given in terms of invariance under geometrical operators, and basic spectral properties will be discussed (e.g., absence of stop-bands)
2. Formulation of electromagnetic problems in higher-symmetric structures: differences between higher-symmetric and periodic structures (30 minutes)
   The role of coupling through higher-order modes among higher-symmetric scatterers will be discussed in order to derive a formulation which can be used with commercial software and explains the difference between periodic structures with and without higher symmetries. The use of circuit models for higher symmetries will be presented.
3. An example of application: modes in a glide symmetric holey metasurfaces by means of a mode-matching approach (15 minutes)
   A mode-matching based on the solution of the glide boundary conditions will lead to obtain a dispersive relation of the modes supported by glide-symmetric metasurfaces. Properties of Floquet harmonics, bandwidth of operation in passband and in stopbands will be discussed, together with possible anisotropic effects.
4. 15-minute questions (possibly at the end of each presentation)
5. Short break
6. Higher-symmetric metasurfaces for flat lenses (40 minutes)
   The use of higher-symmetric unit-cells to mimic artificial materials whose refractive index is stable over an ultrawide band of frequencies will be explained. A design flow and simple rules will be provided to synthesise the desired lens.
7. Novel EBG materials with higher symmetries (35 minutes)
   The effect of higher symmetries on stop-band will prove their interest to realize EBG materials with enhanced performances with respect to standard techniques. Different microwave circuits will be discussed in detail.
8. 15-minute questions (possibly at the end of each presentation)

Instructor 1 – Biograohy

Guido Valerio received his Ph.D. degree in electromagnetics from the Sapienza University of Rome, Rome, Italy, in 2009. From 2011 to 2014, he was a Researcher with the IETR, Rennes, France. Since 2014, he has been an Associate Professor with the Electronics and Electromagnetism Laboratory (L2E), Sorbonne Universités, Université Pierre et Marie Curie, Paris, France. He was a Visiting Scholar at the University of Houston in 2008 and at the University of Michigan in 2015, 2016, and 2017.

His research interests include numerical methods for wave propagation and scattering in complex structures, leaky-wave antennas, SIW, multi-layered media. He is currently working on wave propagation along artificial surfaces having geometrical higher symmetries. He is co-author of more than 50 papers in international journals, and more than 100 in international conferences. He was the co-organiser of three convened sessions on higher symmetries (at AP-S 2017, EuCAP 2018, and META 2017). He is currently the Main proponent of the COST Action CA18223 on higher-symmetric artificial materials.

Dr. Valerio was a recipient of the Leopold B. Felsen Award in 2008. In 2010, he was a recipient of the Barzilai Prize for the best paper at the National Italian Congress of Electromagnetism (XVIII RiNEm). In 2014, he was a recipient of the Raj Mittra Travel Grant for junior researchers presented at the IEEE Antennas and Propagation Society Symposium, Memphis, TN, USA. In 2018, he was co-author of the best paper in “Electromagnetic and Antenna theory” at the 12th European Conference on Antennas and Propagation (EuCAP), London, UK.

Instructor 2 – Biography

Oscar Quevedo-Teruel received his degree in Telecommunication Engineering from Carlos III University of Madrid Spain in 2005, part of which was done at Chalmers University of Technology in Gothenburg, Sweden. He obtained his PhD from Carlos III University of Madrid in 2010 and was then invited as a postdoctoral researcher at the University of Delft (The Netherlands). From 2010-2011, Dr. Quevedo-Teruel joined the Department of Theoretical Physics of Condensed Matter at Universidad Autonoma de Madrid as a research fellow, and went on to continue his postdoctoral research at Queen Mary University of London from 2011-2013. In 2014, he joined the Electromagnetic Engineering Division, in the School of Electrical Engineering and Computer Science at KTH Royal Institute of Technology in Stockholm, Sweden where he is an Associate Professor and director of the Master Programme in Electromagnetics Fusion and Space Engineering. He is an Associate Editor of the IEEE Transactions on Antennas and Propagation since 2018, and he is the delegate of EurAAP for Sweden, Norway and Iceland for the period 2018-2020. He is a distinguished lecturer of the IEEE Antennas and Propagation Society for the period 2019-2021.
He has made scientific contributions to higher symmetries, transformation optics, lens antennas, metasurfaces, leaky wave antennas, multi-mode microstrip patch antennas and high impedance surfaces. He is the co-author of 77 papers in international journals, 140 at international conferences and has received approval on 3 patents.

Key bibliography

[1] Hessel, M. H. Chen, R. C. M. Li, and A. A. Oliner, “Propagation in periodically loaded waveguides with higher symmetries,” Proceedings of the IEEE, vol. 61, no. 2, pp. 183–195, Feb 1973.
[2] O. Dahlberg, R. C. Mitchell-Thomas, and O. Quevedo-Teruel, “Reducing the dispersion of periodic structures with twist and polar glide symmetries,” Scientific Reports, vol. 7, no. 1, p. 10136, 8 2017.
[3] O. Dahlberg, F. Ghasemifard, G. Valerio, and O. Quevedo-Teruel, “Propagation characteristics of periodic structures possessing twist and polar glide symmetries,” EPJ Applied Metamaterials, vol. 6, p. 14, 2019.
[4] D. Cavallo and C. Felita, “Analytical formulas for artificial dielectrics with nonaligned layers,” IEEE Transactions on Antennas and Propagation, vol. 65, no. 10, pp. 5303–5311, Oct 2017.
[5] O. Quevedo-Teruel, M. Ebrahimpouri, and M. N. M. Kehn, “Ultrawideband metasurface lenses based on off-shifted opposite layers,” IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 484–487, Dec 2016.
[6] O. Quevedo-Teruel, J. Miao, M. Mattsson, A. Algaba-Brazalez, M. Johansson, and L. Manholm, “Glide-symmetric fully metallic Luneburg lens for 5G communications at Ka-band,” IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 9, pp. 1588–1592, Sept 2018.
[7] M. Ebrahimpouri, O. Quevedo-Teruel, and E. Rajo-Iglesias, “Design guidelines for gap waveguide technology based on glide-symmetric holey structures,” IEEE Microwave and Wireless Components Letters, vol. 27, no. 6, pp. 542–544, June 2017.
[8] E. Rajo-Iglesias, M. Ebrahimpouri, and O. Quevedo-Teruel, “Wideband phase shifter in groove gap waveguide technology implemented with glide-symmetric holey EBG,” IEEE Microwave and Wireless Components Letters, vol. 28, no. 6, pp. 476–478, June 2018.
[9] M. Ebrahimpouri, A. A. Brazalez, L. Manholm, and O. Quevedo-Teruel, “Using glide-symmetric holes to reduce leakage between waveguide flanges,” IEEE Microwave and Wireless Components Letters, vol. 28, no. 6, pp. 473–475, June 2018.
[10] G. Valerio, Z. Sipus, A. Grbic, and O. Quevedo-Teruel, “Accurate equivalent-circuit descriptions of thin glide-symmetric corrugated metasurfaces,” IEEE Transactions on Antennas and Propagation, vol. 65, no. 5, pp. 2695–2700, May 2017.
[11] M. Bagheriasl, O. Quevedo-Teruel, and G. Valerio, “Bloch analysis of artificial lines and surfaces exhibiting glide symmetry,” IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 7, July 2019.
[12] M. Bagheriasl and G. Valerio, “Bloch analysis of electromagnetic waves in twist-symmetric lines,” Symmetry, vol. 5, no. 1, p. 620, 2019.
[13] G. Valerio, F. Ghasemifard, Z. Sipus, and O. Quevedo-Teruel, “Glide-symmetric all-metal holey metasurfaces for low-dispersive artificial materials: Modeling and properties,” IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 7, pp. 3210–3223, July 2018.