Ph.D. thesis

Dispersion-engineered metalenses for high-performance low-profile antennas and extreme wave manipulation

Context and description of the work

The performance of conventional antenna architectures, e.g. phased arrays, dielectric lenses and reflectors, is often limited by inherent trade-offs among bandwidth, efficiency, scan range and size. Disruptive and versatile concepts will be soon necessary to address the diverse and demanding requirements arising in new applications such as satellite communications, beyond-5G networks and high-resolution imaging.

In the last decade, metasurfaces [1]-[4], i.e. electrically thin arrays of subwavelength scatterers, emerged as a groundbreaking solution to manipulate at will an incident wavefront and enable unprecedented performance and functionalities for radiating and focusing systems.

The subwavelength periodicity of a metasurface provides an extremely fine control on the phase and amplitude of the aperture field, as compared to standard half-wavelength-spaced antenna arrays. Therefore, a metasurface can precisely introduce abrupt field discontinuities and achieve, based on Huygens' principle, arbitrary transformations of the incident field within extremely thin regions [3].
However, the periodic arrangement of the elements and their frequency dispersion significantly narrow the operating bandwidth of metasurface antennas and components. Achromatic metalenses [4] have been demonstrated only at optical frequencies by independently controlling phase and group delays of three-dimensionsional meta-atoms and using complex micromachining processes. In the microwave and millimeter-wave range, state-of-the-art techniques for the broadband and multiband design of metasurface antennas lead to severe gain and efficiency degradation [5].
Moreover, even though anisotropy is essential to mold the angular response of metasurface and the polarization of the scattered fields [3], [6], only early-stage models and synthesis methods have been proposed for highly anisotropic two-dimensional metasurfaces.

This Ph.D. thesis aims to develop novel procedures for engineering the dispersion of metasurface lenses and to demonstrate, both numerically and experimentally, the benefits of this solution for a wide range of advanced low-profile antenna systems, in terms of aperture efficiency, scanning performance and bandwidth.

The mathematical model will resort to the homogenization of the metasurface [3], treated as an effective medium, and apply generalized sheet transition conditions to compute the scattered fields. The general case of fully bianisotropic metasurfaces will be investigated, considering several canonical and realistic excitations, e.g. plane and spherical wave, simple antenna feeds.

Based on the direct model, two synthesis procedures will be developed to:
(i) engineer the frequency response of a large metalens without significantly degrading its efficiency;

(ii)   tailor the effective refractive index of a bianisotropic metasurface as a function of the incident angle of the impinging wave.

The synthesis tool will be exploited for the design of demonstrators operating at microwave frequencies, with the aim of reaching high gain and extended field of view.

At least one of the demonstrators will be prototyped and experimentally validated.

Skills required

- The candidate must have completed a master degree in electrical engineering, physics or applied mathematics.
- Strong background in electromagnetic theory (fundamental theorems, modal and plane-wave expansions, transmission lines) and antennas (dipole and aperture antennas, arrays).
- Experience with one or more electromagnetic simulation software (e.g., HFSS, CST, Feko).
- Good knowledge of one or more programming languages for scientific computation (e.g., Matlab, Python, C, Fortran).
- The candidate should be fluent in English, hard-working, passionate about research and able to work both independently and in a multicultural team.
- Previous experience on periodic media and/or metamaterials will be a plus.

Host laboratories and availability of the position

The candidate will mainly carry out her/his research activities at:

CEA – Leti, *Laboratory of Antennas, Propagation and Inductive Coupling*,

17 av. des Martyrs, Minatec Campus, 38054 Grenoble, France.

She/He will be enrolled in the Ph.D. program of:

Ecole doctorale SMAER, *Sorbonne Université*, Paris, France.

Ph.D. duration: 3 years. full-time contract. Starting date: Autumn 2021.

Application and Ph.D. supervision

Interested candidates should send an e-mail with a detailed CV, academic transcripts and the contact information of at least one referee, to:

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References

[1] C. Pfeiffer and A. Grbic, "Metamaterial Huygens' surfaces: tailoring wave fronts with reflectionless sheets", *Phy. Rev. Lett.* 110, 197401 (2013).

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[3] F. C. Cuesta, I. A. Faniayeu, V. Asadchy, and S. A. Tretyakov, "Planar broadband Huygens' metasurfaces for wave manipulations", *IEEE Trans. Antennas Propag.* vol. 66, no.12, Dec. 2018.

[4] W. Chen, A. Zhu, J. Sisler, Z. Bharwan, and F. Capasso, "A broadband achromatic polarization-insensitive metalens consisting of anisotropic nanostructures", *Nat. Commun.* 10, 355 (2019).

[5] M. Faenzi, D. Gonzalez-Ovejero, and S. Maci, "Wideband active region metasurface antennas", *IEEE Trans. Antennas Propag.* vol. 68, no.3, Mar. 2020.

[6] M. Chen and G. V. Eleftheriades, "Omega-bianisotropic wire-loop Huygens' metasurface for reflectionless wide-angle refraction", *IEEE Trans. Antennas Propag.* vol. 68, no.3, Mar. 2020.