**PhD Thesis Subject: Complex analysis of Optical Spectral Responses for Determining the Spectral Phase of Photonic Components**

**Hosting laboratory**: Institut Fresnel

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**PhD thesis description**: The optical responses of components can be characterized by the scattering matrix *S*. Studying the evolution of the elements of the *S*-matrix as a function of frequency provides valuable information about the component. A very interesting approach consists of studying these elements in the complex frequency plane. These elements are meromorphic functions that may have poles and zeros in the complex frequency plane, which correspond to complex frequencies where these functions become infinite and null, respectively. It is possible to reconstruct these meromorphic functions from their poles and zeros using an analytical expression known as the Singularity Expansion Method [1]. Knowing the poles and zeros allows the retrieval of the spectral response of the *S*-matrix elements and the determination of the amplitude and phase responses of scattering elements for all frequencies. These parameters are essential for optimizing the response of metasurfaces. Phase plays a crucial role in these components, which aim to modify the amplitude, phase, and polarization of light beams using resonant elements [2]. Despite significant efforts to understand the phase difference associated with the resonance of scatterers or an assembly of scatterers, recent theoretical advancements show that it is possible to determine this phase difference in the spectral domain of interest based on the poles and zeros of the *S*-matrix elements [3].

The first part of the PhD work will focus on studying the phase modification introduced by various scatterers or assemblies of scatterers and constructing a metasurface with the required properties by combining these different elements. Various applications of these metasurfaces will be explored, particularly in controlling their spectral response and in the creation of holograms.

The second part of this work will use the Singularity Expansion Method to analyze the spectral response of components. The goal will be to deduce the distributions of poles and zeros in the complex frequency plane from measurements taken at real frequencies [4]. This project will require combining theoretical analysis and numerical tools with experimental measurements of spectra and phases. Knowledge of these distributions will yield highly relevant fits for spectral responses, and studies will be carried out for extracting the signal, filtering the noise, and recovering phase information from the measured element of the S matrix across the entire spectral window.

**References:**

[1] I. Ben Soltane, R. Colom, F. Dierrick, B. Stout, N. Bonod, “Multiple-Order Singularity Expansion Method,” New J. Phys. **25**, 103022 (2023)

[2] A.I. Kuznetsov, M.L. Brongersma, et al. “Roadmap for optical metasurfaces,” ACS Photonics **11**, 816 (2024)

[3] I. Ben Soltane, N. Bonod, “Extracting Complete Resonance Characteristics From the Phase of Physical Signals,” arXiv (2024)

[4] I. Ben Soltane, F. Dierick, B. Stout, N. Bonod, “Generalized Drude-Lorentz Model Complying with the Singularity Expansion Method,” Adv. Optical Mater. **12**, 2400093 (2024)