Numerical Techniques for the Automated Design of Metasurface Antennas

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Declaration

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2022

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This thesis presents the theory and development of a novel approach for the automated design of metasurface antennas. The introduced method is fully numerical and can be applied to the design of 3D metasurfaces, allowing the transformation of a given incident field into a radiated field that satisfies mask-type amplitude constraints.

The design of metasurfaces is challenging due to their intrinsic multi-scale features, as they are composed by many subwavelength scattering elements. The process is made possible by the introduction of macroscopic models that describe the behaviour of the metasurface in terms of an equivalent *impedance boundary condition* (IBC), which defines the relationship between the tangential electric and magnetic fields on either side of the metasurface. To be implemented in practice, the obtained impedance must be *realizable*, i.e., it must be passive and lossless, with reactance values within practical manufacturing limits.

In this work the focus is on the *macroscopic* design of metasurfaces, i.e., the design of the surface impedance profile that leads to the desired radiated field. Common techniques for the macroscopic design of metasurface antennas rely on analytical approximations for the incident and scattered fields, as well as for the impedance profile. This limits their application to simple geometries, and the ability to deal with arbitrary specifications is minimal. To overcome these limitations, recently new approaches have been proposed which frame the design as an inverse source problem, allowing more generality in the definition of the incident and scattered fields. However, they are formulated as an input-output field transformation on the two sides of a metasurface, preventing their application to cases where the incident field is on the surface (e.g., surface wave based metasurface antennas).

The method introduced in this work is based on a formulation of the scattering problems as an *integral equation*, where the unknown is the equivalent electric current only. The process involves the synthesis of this current, constrained to correspond to a realizable impedance, and to radiate a field obeying the requirements. The impedance is obtained from the synthesized current only at the end of the process. This method requires no a-priori information or heuristics on the impedance distribution.

The current-based design avoids the solution of the forward problem at each iteration, greatly reducing the computational burden, and the formulation is such that all relevant operations in the iterative process can be evaluated with $O(N \log N)$ complexity, where N is the number of unknowns for the current. Another benefit is the ability to enforce mask-type (inequality) constraints, as opposed to pattern matching techniques adopted by previous methods, allowing to incorporate all relevant figures of merit (gain, side-lobe levels, polarization ratio, etc.) directly into the design instance.

To demonstrate the validity of the proposed method, it has been applied to the design of metasurface antennas of practical relevance. Application examples concentrate on the case of on-surface incident field and far-field pattern specifications in terms of realized gain. The obtained results confirm the feasibility of the macroscopic design for medium- and large-size circular metasurfaces, with pencil- and shaped-beam patterns, and for both linear and circular polarization. Design examples for different geometries, i.e., elliptical and symmetric strip, are also included to demonstrate the flexibility of the approach.