Closed-form Characteristic Basis Functions for Metasurfaces

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A metasurface is a thin metamaterial layer characterized by unusual reflection properties of plane waves and/or dispersion properties of surface/guided waves. Metasurfaces can be realized at microwave frequencies by printing a dense periodic texture of small elements on a grounded slab, with or without shorting vias. These structures have been widely used for realizing electromagnetic bandgap (EBG) surfaces or equivalent magnetic-walls. Modulated metasurfaces can be obtained by gradually changing the geometry of the elements in contiguous cells, while maintaining the period unchanged and very small in terms of a wavelength. This modulation can be used to engineer the interaction of a given incoming field with the metasurface, thus realizing a large class of devices like planar lenses or leaky wave antennas (S. Maci, G. Minatti, M. Casaletti, M. Bosiljevac, IEEE Antennas Wireless Propag. Lett., 10, pp. 1499 – 1502, 2011).

The full-wave characterization of metasurface-based devices can be performed using a method of moments solution of a mixed-potential integral equation. Then, the presence of the grounded slab is accounted for through its Green's functions and the unknowns may be limited to the metalizations. Nevertheless, the large number of unit cells involved and the presence of fine mesh details in the sub-wavelength elements make necessary the use of efficient pre-conditioners to get a fast convergence of iterative solvers. This can be a cumbersome process, even when the matrix-vector products are efficiently evaluated using a Multilevel Fast Multipole scheme. Hence, the development of ad-hoc simulation tools is a fundamental asset to foster the development of this useful electromagnetic technology. In the first instance, one may try to characterize each unit cell as a reduced set of current distributions or characteristic basis functions (CBFs). The CBF method leads to a reduction in the number of unknowns, improves the condition number and enables an efficient calculation of reaction integrals, after a preprocessing step. Unfortunately, CBFs generation becomes inefficient for a large number of different cells, as it is the case of metasurfaces.

The idea here is to exploit the a-priori knowledge about the unit cell geometry to choose entire-domain basis functions with special scaling and analytical properties. Indeed, the use of functions with closed-form Hankel transform will help to obtain analytical expressions for the integrals involved in the construction of the MoM impedance matrix. Actually, in the spectral domain, the MoM matrix entries, which are single integrals over an infinite domain, can be cast into closed forms with the help of the generalized pencil of functions or rational function fitting methods.