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Controlled Scattering of Time-Domain Pulses by Metasurfaces: An FDTD Approach

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Metasurfaces (MS) configure as a flat structures of sub-wavelength components designed to manipulate electromagnetic waves according to specific requirements. These components are usually smaller than the wavelength of the incoming electromagnetic wave. The MS are deliberately crafted to precisely shape the phase, amplitude, and polarisation of reflected and/or transmitted waves. The analysis of MS involves various methods to understand and characterise their electromagnetic behaviour. The choice of the appropriate technique depends on factors such as the complexity of the Metasurface structure, the frequency range of interest, and the desired level of accuracy required by the analysis. The MS are typically thinner than the wavelength of the operating frequency. Therefore, their planar structure can be modelled as an equivalent zero-thickness sheet, and might exhibit bi-anisotropy as well as variation in both space and time. Regrettably, no commercially available software currently exists that can model equivalent sheets self-consistently, and analyse such intricate surface boundary conditions, particularly in the time domain.

One of the most powerful methods, the finite-difference time-domain (FDTD) method, can be extended to include equivalent impedance sheets. The application of the FDTD method is feasible to examine the temporal evolution of MS properties, facilitating the analysis of how non-sinusoidal plane waves interact with the equivalent sheet.

In order to model impedance sheets, we employ an augmented version of the canonical FDTD mesh with virtual nodes before and after the thin meta-surface current sheet. We then apply generalised sheet transition boundary conditions to the field components tangential to the sheet, and through discretised Maxwell's equations we get the updated numerical scheme at the virtual nodes.

We verify the modified FDTD scheme for selected MS - under a sinusoidal plane wave excitation - by comparing the frequency domain reflection and transmission coefficients with the closed-form expression available in the scientific literature.

Finally, we investigate the scattering of a time-domain pulse intro anomalous directions and tackle the space-time sheet profile to achieve near-field focusing of interest in beyond 5G network technologies.