Digital Metasurfaces Based on Spatio-Temporal Coding

Lei Zhang[(1)], Xiao Qing Chen[(1)], Shuo Liu[(1)], Qian Zhang[(1)], Jie Zhao[(1)], Jun Yan Dai[(1)], Guo Dong Bai[(1)], Xiang Wan[(1)], Qiang Cheng[(1)], Giuseppe Castaldi[(2)], Vincenzo Galdi*[(2)], Tie Jun Cui[(1)]
(1) Southeast University, Nanjing 210096, China
(2) University of Sannio, I-82100 Benevento, Italy

Digital metasurfaces (T. J. Cui *et al.*, Light Sci. Appl. 3, e218, 2014), relying on a limited number of element types, have established themselves as attractive alternatives to conventional gradient-based configurations. In the possibly simplest scenario, only two element types are utilized, e.g., characterized by out-of-phase reflection/transmission coefficients, which can be associated with a "1/0" *binary coding*. This still enables sophisticated wavefront manipulations, and also establishes an intriguing connection with information theory. Moreover, the possibility of reconfiguring a single element (via active elements such as diodes) so as to switch from a "0"-type to "1"-type response, renders the architecture very versatile and possibly *programmable*, e.g., via field-programmable gate arrays (FPGAs).

So far, *spatial coding* has been extensively explored in order to attain a variety of advanced field manipulations, including beam shaping, reprogrammable holograms, and diffuse scattering. On the other hand, the *temporal* dimension has been largely overlooked. Also in view of the steadily growing interest in time-varying metamaterials, it appears therefore suggestive to explore the potentials of temporal modulation in conjunction with digital metasurfaces.

Recently, we put forward the idea of *space-time-coding* digital metasurfaces (L. Zhang *et al.*, Nat. Commun. 9, 4334, 2018), by cyclically switching (via an FPGA) a set of coding sequences in a given time interval. Here, we briefly review the main outcomes from this study. Essentially, we showed that the proposed space-time-encoded architecture enables simultaneous manipulations of electromagnetic waves in both space and frequency domains, i.e., to simultaneously tailor both the propagation direction and harmonic power distribution. As proof of principle examples, we demonstrated harmonic beam steering, where different frequency components are routed toward prescribed directions. These results were also validated experimentally, at microwave frequencies, demonstrating a good agreement between theoretical predictions and measurements. Moreover, we also demonstrated advanced beam-shaping capabilities (via the synthesis of vortex beams), and diffuse scattering. Current studies are aimed at extending the approach so as to engineer nonreciprocal effects, as well as at exploring possible applications to wireless communications, cognitive radars, adaptive beamforming, and holographic imaging.