Efficient Focusing on Transient Field through Highly Diffusive Random Media

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Many engineering and scientific applications require focusing of electromagnetic fields after they pass through random media. Examples include, but are not limited to, bio-imaging, nondestructive testing, and hyperthermia treatment. In recent years, significant progress has been made on focusing methods that compensate for a field's passage through random media. These so-called wavefront shaping techniques exploit the existence of "open channels" through which random media allow for near-perfect transmission of carefully tailored incident waves. Wavefront shaping techniques come in many flavors. Some assume full amplitude-phase control of the incident field while others presume phase-only modulation; the latter is the norm in the optical regime. Wavefront shaping techniques also differ in the kind of foci they achieve: some seek maximum contrast as opposed to non-contrast foci while others yield maximal-total-intensity as opposed to even-intensity (fair) foci.

Recently, we proposed a family of methods that comprehensively tackle the wavefront shaping problem by leveraging eigendecompositions, convex optimization, and bisection search algorithms (H. Guo et al., Radio Science Meeting USNC-URSI, 2017). Specifically, eigendecompositions are used to handle simple focusing problems when full phase-amplitude modulation is achievable while convex optimization and bisection search are invoked for focusing problems lacking closed form solutions. We furthermore applied these methods to 3D random media composed of multilayer periodic slabs containing randomly positioned metallic particles that are thousands of wavelengths thick.

Unfortunately, most wavefront-shaping techniques proposed to date only exploit the field's spatial degrees of freedom and therefore only yield satisfactory results over a narrow frequency range. In reality, the target may require a pulsating illumination for a specified duration. Here, to accommodate such applications, we develop efficient focusing schemes for transient fields. Specifically, we present a set of schemes for creating a single or multiple pulsating space-time focus/foci. By optimally exploiting the added temporal degrees of freedom, the proposed schemes achieve even tighter spatial foci than achievable using narrowband signals. The proposed schemes first decompose wideband signals into uncorrelated spectral components, each of which is modulated to construct an optimal single frequency wavefront. Next, leveraging Fourier transform methods, optimal single frequency wavefronts are superimposed to construct foci at desired locations and pre-specified times. Not unlike our previous frequency-domain methods, the new time-domain techniques apply to scenarios that allow for phase/delay-only as well as full phase/delay-amplitude modulation of the incident wavefront. We demonstrate the scheme's ability to create multiple pulsating asynchronous or simultaneous foci after passing through 3D random media composed of multilayer periodic slabs.