Efficient Multi-Point Field Focusing Through Highly Diffusive Random Media

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The need to focus electromagnetic fields passing through random media arises in applications ranging from bio-imaging to nondestructive inspection and electromagnetic hyperthermia treatment, to name but a few. Unfortunately, conventional focusing techniques are very inefficient when used for highly diffusive media composed of small scatterers that significantly alter the path the fields travel along, either causing speckle patterns in the exit aperture or preventing penetration altogether. Previously, we demonstrated the possibility of "perfect transmission" of waves passaging through so-called "open channels" in lossless dilute random media by using wavefront shaping techniques in both 2D and 3D (C. Jin et. al., *J. Opt. Soc. Am. A*, 30(8), 1592-1602; H. Guo et. al., *Proc IEEE Int. Symp. Antennas Propagat.,* 2016).

Can wavefronts of fields impinging on random media be shaped to optimally couple into these "open channels" and create focused fields upon exit? Previously, we answered this question in the affirmative by using a Lanczos-based algorithm to focus fields passing through thick slabs infused with random metallic scatterers (C. Jin et. al., *J. Opt. Soc. Am. A*, 30(8), 1592-1602; H. Guo et. al., *Proc IEEE Int. Symp. Antennas Propagat.,* 2016). Unfortunately, the scheme calls for full amplitude and phase control of the incident wave. In many practical situations, only the phase of the field can be efficiently controlled; this is especially true in the optical regime where control is achieved using phase-only spatial light modulators (SLMs). Furthermore, the scheme is limited in the type and number of foci it is capable of producing.

Here, we present a new family of highly efficient focusing schemes capable of creating multiple foci under a variety of conditions of practical interest. Our schemes apply to scenarios that allow for phase-only as well as full phase-amplitude modulation of the incident wavefront, and suit problems requiring contrast and non-contrast as well as maximal-total-intensity and even-intensity (fair) focusing. The proposed schemes comprehensively tackle the wavefront shaping problem by leveraging eigendecompositions, convex optimization, and bisection search algorithms. 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 demonstrate the new focusing schemes' capabilities and efficiency by applying them to 3D random media composed of multilayer periodic slabs containing randomly positioned metallic particles that are thousands of wavelengths thick.