Beam formation for enhancing early-time diffusion in short optical pulse propagation through random particulate media

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Imaging and communication with short pulses through random particulate media (e.g., atmospheric clouds, fog, etc.) is known to be severely hampered by scattering-induced diffusion, causing pulse spatial spreading in space and time. A recently described phenomenon of early-time diffusion (E. Bleszynski, M. Bleszynski, and T. Jaroszewicz, Optics Letters, vol. 39, pp. 5862-5865, 2014) offers a possibility of mitigating these difficulties by isolating, in the time-resolved intensity of the received pulse, a rapidly rising component immediately following the ballistic (coherent) signal, but attenuated at a significantly lower rate. That early-time pulse component is present provided the medium particles are sufficiently large compared to the wavelength, and arises from strongly forward-peaked scattering, giving rise to a persistent random-walk process and a specific "early-time" diffusion behavior.

In the present paper we consider the possibility of enhancing the contribution of the early-time diffusion and of reducing the late-time diffusion component through suitable incident beam formation.

We examine intensities as solutions of the radiative transfer equation (RTE) describing the pulse propagation and represent them as superpositions of eigenmodes of the RTE. We find that, for propagation distances large compared to the mean free path, the pulse intensity is dominated by only a few eigenmodes, belonging to two classes, contributing to (i) the early-time and (ii) the usual late-time diffusion. As the properties of the eigenmodes (i) and (ii) – their distributions in the wave number and in the transverse coordinates – are very different, the field source (the beam shape) may be designed to couple strongly to the modes (i) and only weakly to the modes (ii), thus reinforcing early-time and suppressing late-time diffusion contributions. However, the source distribution, (i.e., its mutual coherence function) cannot be arbitrary and must satisfy the physically mandated positive semi-definiteness condition. We describe preliminary results of source optimization based on its parameterization (analogous to the coherent-mode representation) satisfying the positivity constraints.