Evolution of the early time diffusion component of a short pulse propagating in a sparse random medium *

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Imaging and communication with optical or infrared pulsed signals through obscuring random media (e.g., atmospheric clouds, fog, dust, or aerosols) is a long-standing and challenging problem, both experimentally and theoretically.

From the experimental and applications perspective, a coherently detected pulse field preserves its time profile, but is strongly attenuated, at the rate proportional to the total cross-section of the wave on an individual medium scatterer. The incoherently detected field intensity (or, more generally, the mutual coherence function (MCF)), although attenuated at a lower rate (proportional to the absorption cross-section), develops a long diffusive tail which causes loss of resolution in imaging and loss of bandwidth in communication.

In this contribution we provide a rigorous approach based on analytic complex-contour integration of numerically determined cut and pole singularities of the radiative transport equation solution in the Fourier space. We show that the time-resolved intensity of a short pulse propagating in a sparse random medium composed of scatterers of the size of several wavelenghts, in addition to the coherent ("ballistic") contribution and a long late-time diffusive tail, also exhibits a distinctive early-time enhancement which can be attributed to small angle multiple diffractive scattering on medium constituents. This early-time intensity enhancement is being attenuated proportionally to the non-diffractive rather than the total cross-section, i.e., at the rate lower than the coherent component. It is also characterized by a short rise time approximately inversely proportional to the square of the scatterers size.

The origin of the early-time diffusion component suggests that it should be possible to isolate it by selecting the region of large values of the relative wave number variable P (Fourier conjugate to the observation midpoint variable R) in the Fourier-space intensity; this amounts to high-pass filtering of the received time-domain intensity.

We discuss the dependence of the early-time intensity component on such medium properties as sizes and velocities of the scatterers. We find that the Doppler frequency shift caused by the motion of scatterers, as well as the cross-section variations in the optical Mie resonance regime, have relatively insignificant effect on the early diffusion component of the intensity.

Our results may have important implications in high-resolution range imaging as well as communication through obscuring (atmospheric clouds, fog, dust, or aerosols) media.