Ray Diffusion through a Turbulent Flow with Bipolar Vortex Structures

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There exists an extensive study in the literature on wave propagation through turbulent flow. Depending on the scale size of the fluctuation in terms of the signal wavelength different types of methodologies have been developed and used. For instance, when the scale size is large one can use the WKB method or the geometrical optics method. Flow field turbulence is most often modelled using its power spectral density, which is obtained either from measured data or from direct numerical simulations. Such spectral density can be isotropic or anisotropic, but the most important aspect of this method is that a continuum of wavenumbers are involved in the energy spectrum. Although this method is quite good for fully developed turbulence it is not appropriate for others. For instance, both measured and simulated data corresponding to earlier stages of the onset of turbulence display the formation of long duration coherent structures. The energy in these large structures eventually cascade into smaller structures and finally dissipate into heat. Thus a model for turbulence more appropriate during the earlier stages should be based on vortex structures. In this paper we study the impact of bipolar vortex distributions on signal propagation.

Our interest is in the high frequency regime and hence we employ the Hamilton-Jacobi equations for tracking the dynamics of the signal in the turbulent flow. In this regime, signal scattering takes place predominantly in the forward region. Hence, we find that the evolution of the probability density function (pdf) in phase space is governed by the Fokker-Planck (FP) equation whose coefficients are calculated using the Hamilton-Jacobi equations. The background medium is assumed to be homogeneous and hence the friction coefficient vanishes. This also leads to space invariant diffusion tensor. The diffusion tensor calculation for flow with bipolar vortices is significantly more complicated compared unipolar Gaussian vortices. A major part of our effort was spent in the evaluation of the diffusion tensor for our problem. Details of our procedure and the approximations made will be elaborated at the conference. We hence arrive at a diffusion equation which can be solved using transform methods. With the availability of the pdf, several measures of signal propagation can be calculated. One of the quantities of interest is the beam-pointing error induced by the turbulent flow. For the case of monopolar Gaussian vortex distribution we find that the rms pointing error is independent of the angle of incident beam. For the case of bipolar vortex distribution the rms error strongly depends on the angle of the incident beam. Moreover the orientation of the bipolar vortices is an important parameter that affects beam propagation. We will provide some numerical examples to illustrate the characteristics of signal propagation through the turbulent flow. Although there are several different theoretical methods for this problem, the FP approach is perhaps the most efficient for studying long range signal propagation through large scale structures.