Controlling Transmission Through Random Media: Channels and Modes

V. Freilikher

Scattering on random variations of electrodynamic parameters that are ubiquitous in any natural media or tailor-made structures has a pronounced (sometimes determining) impact on the propagation of microwaves, light, acoustic waves, etc. Channeling of radiation trough transmission eigenchannels and resonant quasi-normal modes are the dominant mechanisms of wave propagation in fluctuating environment. In this presentation, I'll show that although the effects of disorder are usually destructive, causing unwanted losses of energy and coherence of transmitted signals, the random scattering, being treated properly, can be put to use to control the reflection from and transmission through random media, to improve remote sensing algorithms, etc.

When a wave is incident on a *diffusive* disordered medium, it is decomposed into a number of "partial waves" that propagate independently along the so-called transmission eigenchannels (TEs), and are superposed again at the receiving side. The shape of each channel is preserved all along the sample, including the output, which means that signal does not spread in the process of propagation. At the same time, the longitudinal profile of the energy density distribution of TEs is universal. It is given by an analytical formula, in which the details of the system, such as the geometry and the disorder parameters, enter only into the ratio L/l, where L is the distance of propagation and l is the scattering mean free path. The important implication is that TEs can be harnessed to suppress reflection in favor of transmission, and vice versa. This is because the probability distribution of the transmission coefficients τ is bimodal – it is picked at $\tau = 1$ and $\tau = 0$, corresponding to highly transparent and reflecting channels, respectively. By specific processing of the radiated signal it is possible to redistribute the energy between appropriated channels in order to significantly enhance (or suppress) the delivery of energy to the receiver. It also means that a diffusive medium can be utilize to increase spatial resolution even beyond the diffraction limit.

In the *localized regime*, which is typical for long enough one-dimensional media, the transmission eigenchannels do not exist, and typically such systems are exponentially (with respect to length) non-transparent, except for the discrete set of frequencies, at which disorder-induced transmission resonances occur. Although, strictly speaking, a disordered 1D system is a mathematical abstraction, it can provide an adequate model for many actual physical objects. Randomly stratified media, which from mathematical point of view can be treated as one-dimensional ones, are found in numerous atmospheric, geological, hydro-acoustical, and biological settings, as well as in fabricated materials. In particular, the interference of multiply-scattered waves can make a crucial impact on the far-beyond-the-horizon propagation of microwaves in the troposphere. Indeed, in 3D randomly stratified media, the one-dimensional (in the vertical direction) localization leads to formation of disorder-induced fluctuational waveguides, along which the radiation propagates with anomalously small attenuation. The estimations show that, for example, in tropical zones at anticyclone conditions, this mechanism can contribute significantly to the far-beyond-the-horizon microwave propagation along the ocean surface. Although no thorough measurements aimed at observing the fluctuation waveguide have yet been carried out, some indirect evidences in favor of this phenomenon do exist, for example, frequently observed correlation of the over-the-horizon field intensity with the dispersion of the refraction index fluctuations near the surface. While the origins of TE and TR are different, their special shapes are well described by the same analytical expression. The physical nature of this surprising universality is not yet completely understood.