Effect of atmospheric turbulence on modulational instability in laser-pulse propagation

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Multiple filamentation is a major problem for laser pulse propagation in the atmosphere. In this article, we study the influence of a turbulent atmosphere on the growth of the modulational instability which is the cause of multiple filamentation. It is shown, analytically and numerically, that the growth rate of this instability is reduced by considering that the index of refraction has a stochastic behavior. A good qualitative agreement between the analytic and numerical results is obtained. A better understanding of the propagation of very powerful short laser pulses is a crucial issue for its wide range of applications in the remote sensing of chemical and biological agents as well as in directed energy applications, induced electrical discharges, lightning protection, long-range propagation of light. For instance, the LIDAR (light detection and ranging) technique is an effective tool to investigate the atmosphere pollutants.

At high laser powers, when the laser power is higher than the critical power $P \gg P_{cr}$, the input beam, due to unavoidable beam irregularities, breaks up into N filaments, with $N = P/P_{cr}$, each of them carrying about the critical power. Chaotic bundles of filaments are formed, and an erratic backscattering signal is observed. This multiple filamentation can play a positive or negative role depending on what we want to measure or the application we are targeting. Lightning discharge control requires long homogeneous plasma channels which are produced by the filament. The detected backscattered nitrogen fluorescence from inside the filaments yields irregular changes from shot to shot which cannot be explained by fluctuation resulting from the initial laser pulse itself. This irregularity is not only due to the difference in signal profiles, but also in certain shots where no significant signal is detected. Thus, for many applications, filamentation control is an important issue and there exists a challenge in controlling the modulational instability.

We show that the growth rate of the Bespalov and Talanov instability is reduced by turbulence outlined by introducing a stochastic refractive index in the nonlinear Schrödinger equation. A stochastic differential equation is solved considering refractive index. A rough approximation used to average the Green's function of the set of equations is legitimized by deriving, in one case, the same result with an exact calculation. The theoretical results are supported by numerical integration of basic equations. We highlight a trend, filamentation should be less important when the atmosphere is turbulent allowing a more homogeneous light beam.