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Numerical Prediction of Incoherent Modulation Instability Dynamics through Deep Learning Approaches

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In nonlinear fiber optics, Modulation Instability (MI) is characterized by the emergence of new spectral components, either seeded from optical signals or appearing spontaneously from noise amplification. MI then constitutes an ideal playground for studying complex and incoherent nonlinear propagation dynamics [1]. In recent years, Artificial Neural Networks (ANN) have been used to characterize nonlinear dynamics and investigate ultrafast optical pulse evolution with remarkable accuracy and precision [2,3]. However, few works focused on incoherent optical propagation, with the identification of precursors and key-parameters responsible for the apparition of specific nonlinear phenomena in noise-driven systems [3-5].

Here, we report on a numerical study based on the generalized Nonlinear Schrödinger Equation (GNLSE) [6] used to model nonlinear fiber propagation where two optical seeds compete with broadband noise to drive incoherent MI broadening dynamics (Fig. 1 a). Specifically, we generate a dataset comprising 200,000 propagation scenarios using different optical seed parameters (wavelength and phase). Each propagation scenario is computed 100 times using random input noise, in order to characterize the fluctuation of the output MI spectrum and retrieve the corresponding spectral correlation map and average spectrum. Using this dataset, we trained Feed-Forward Neural Networks (FFNN) to either retrieve the optical seed parameters at the fiber input or to forecast the shape of the average spectrum with an average accuracy of $\sim 98\%$, as shown in Fig. 1 (b) and Fig. 1 (c), respectively.

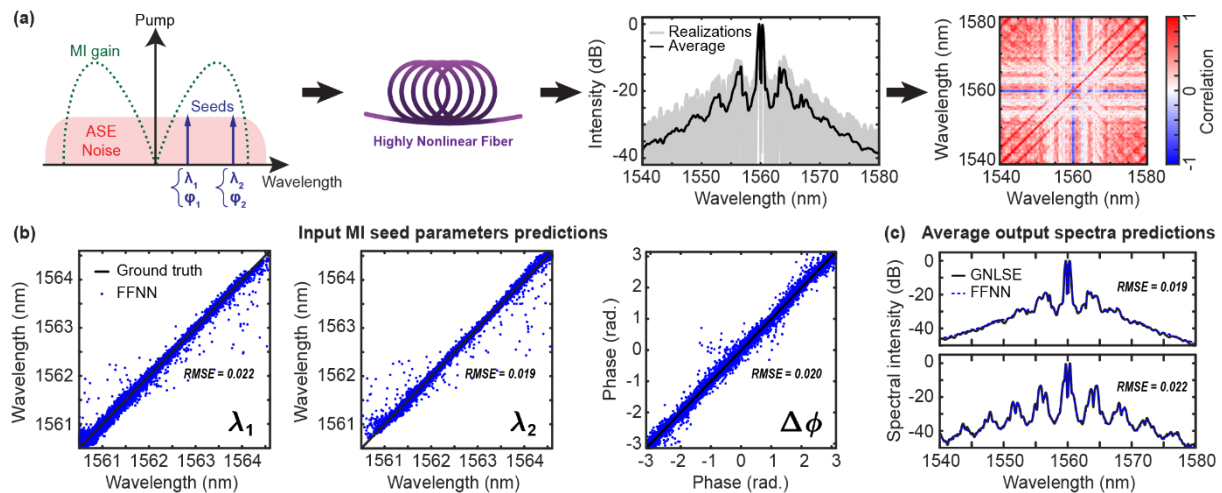


Fig. 1 (a) Schematic of the incoherent induced MI broadening dynamics studied numerically. Two weak optical seeds with adjustable parameters λ_1 , λ_2 , ϕ_1 , ϕ_2 are randomly selected in each case. The fluctuating output spectra, are computed considering different input noise and used to retrieve the average spectrum and the spectral correlation map. (b) Seed parameters prediction (i.e. λ_1 , λ_2 and $\Delta\phi = \phi_1 - \phi_2$) from FFNN training using correlation map measurements. (c) Examples of average output spectra prediction from FFNN training from variable seed parameters.

In this work, we further discuss the potential and limitations of ANN training based on noisy experimental dataset obtained from DFT measurements [7] and study other types of ANN architectures for the retrieval of relevant information on incoherent MI dynamics. We expect this approach to efficiently mitigate experimentally-intense data acquisition for the study of incoherent nonlinear dynamics beyond MI. We also anticipate this work to provide insight into noise-driven nonlinear conversion processes and its potential to conceal relevant optical information.

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