Exceptional Points of Degeneracies in Gain and Loss Balanced Devices

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We present a novel paradigm for dispersion engineering for devices operated at exceptional points of degeneracy (EPDs) using gain and balance condition. EPDs are points in the parameter space of systems at which two or more eigenmodes (eigenvalues and eigenvectors) coalesce into a single degenerate eigenmode. The number of coalescing eigenmodes at the EPD defines the order of the degeneracy. For example, the regular band edge (RBE), the stationary inflection points (SIP), and the degenerate band edge (DBE) are 2^{nd}, 3^{rd} and 4^{th} order EPDs, respectively. EPDs emerge in gain and loss balanced non-Hermitian systems such as those obeying the PT-symmetry; although they may also occur in lossless periodic structures without need for gain and loss.

EPDs were known to be ultra-sensitive to any external perturbations and this sensitivity increases as the order of EPD increases, therefore ideal EPD conditions are difficult to be exactly satisfied in practice. We develop a figure of merit to assess the occurrence of EPD in the presence of tolerances and losses, which we called the hyperdistance. This hyperdistance is useful to assess the quality of such EPD subject to any kind of perturbation in parameter space of the system (like losses, frequency detuning, or tolerances of parameters). A perfect degeneracy condition corresponding to a lossless structure does not exist in practice when losses are present but can be met in an approximate way where the main EPD features of coalescing eigenvectors still retains.

Furthermore, using the developed hyperdistance concept we investigate the “gain and loss balance” regime in CTLs as a mean of recovering an EPD in the presence of radiation and/or dissipative losses, without necessarily resorting to Parity-Time (PT)-symmetry regimes. The EPD concept based on gain and loss balance is promising in applications with large radiation “losses” when adding gain in proper manner. These applications include high intensity and power-efficiency oscillators and spatial power combiners, or low-threshold oscillators and opens new frontiers for boosting the performance of large coherent sources.