Time Variant induced non-reciprocity enhanced by exceptional points of degeneracy

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In recent years we have observed a rise of the concept of time-variant systems with promising potential applications in antennas and microwave circuit devices. In particular, it is demonstrated that time-domain modulation and RF time switching lead to non-reciprocal performance. This has stimulated various applications involving non-reciprocal electromagnetic components, such as isolators, non-reciprocal filters and absorbers, which require breaking the time-reversal reciprocity. Conventionally, the non-reciprocal performance has been achieved using magneto-optical materials such as ferrites. In this paper, we explore non-reciprocal propagation in coupled-waveguides using time-variant lumped or distributed loads; operating at a special degeneracy condition referred to as exceptional point of degeneracy (EPD). This EPD phenomenon entails the coalescence of the eigenstates of the dynamical system at a single point in the parameter space. This has been a surge of interest in applications related to EPD and involving also gain and loss (such as those obeying Parity-Time (PT)-symmetry). Indeed, it has been shown that non-reciprocity in crystal-like structures with ferrites is tremendously enhanced by exploiting the degeneracy of multiple co-propagating modes (A. Figotin and I. Vitebsky, Phys. Rev. B, 67, 16 165210, 2003).

We explore for the first time how the concept of EPD in multi-modal waveguides can be combined with time-variant loads to enhance non-reciprocity effects, in which we show unidirectionality of transmission. We also investigate realization of the EPD with various orders and its impact of the induced non-reciprocity. We utilize a generalized coupled transmission lines (CTLs) theory (V. A. Tamma and F. Capolino, IEEE Trans. on Plasma Science, 42, 899-910, 2014) in time-domain accounting for the time-variant loads. In addition, we show examples of the time-variant loads realizations by periodically loading the CTLs with a bank of capacitors (whose capacitance is modulated by a traveling carrier wave) and switches with certain switching frequency and duty cycle. This enhanced non-reciprocity may find many applications including pulse compression, high-power RF generation, and broadband phase shifters for phased arrays antenna.