Parity-Time-Reciprocal Symmetry in Radio-Frequency Electronics

Maryam Sakhdari and Pai-Yen Chen,

Department of Electrical and Computer Engineering, Wayne State University,

Detroit, MI, 48202, USA.

In this talk, we will present a new concept of parity-time-reciprocal (PTX) symmetry in electronics and electromagnetism, where the parity (P), time (T), and reciprocal (X) operators perform the spatial inversion, time reversal, and reciprocal scaling transformations, respectively. We have theoretically investigated and experimentally shown that a PTX-symmetric radio-frequency (RF) circuit, which although has a non-Hermitian effective Hamiltonian (H_{PTX}), could have purely real eigenfrequencies that are the exactly same as those of a PT-symmetric system with an effective Hamiltonian (H_{PT}). This is because the PTX operator commutes with H_{PTX} (PTX, H_{PTX}] = 0) and H_{PTX} is the similarity transform of H_{PT} ($H_{PTX} = R^{-1} H_{PTX} R$). Here, we have demonstrated the PTX-symmetric system with a RF lumped-element oscillator circuit, consisting of a pair of inductively coupled RLC (attenuation) and –RLC (amplification) dimers. This non-Hermitian electronic system with properly balanced gain and loss is invariant with respect to the combined PTX operators, but changed by P, T, or X individually. Our results show that by manipulating the coupling strength of the amplifying/attenuating dimers and the Hermiticity ($\gamma = R^{-1}\sqrt{L/C}$) of this PTX-symmetric circuit, the spectral bifurcation can be observed, with the phase varied from the broken PTX symmetry (i.e. complex eigenfrequencies with purely amplifying or attenuation effect) to the exact PTX symmetry (i.e. real eigenfrequencies with unique unidirectional reflectionless properties), somehow similar to the conventional PT-symmetric system. In addition, the PTX-symmetric system can have the same eigenfrequencies as the PT-symmetric one, but with different eigenstates that are controlled by the reciprocal operator X, thereby allowing one to manipulate arbitrarily the bandwidth, while locking the operating frequency. More interestingly, by reciprocally scaling the gain and loss of the system under the X symmetry, the exact PTX-symmetry phase with real eigenfrequencies can even be observed in a fully-passive, non-Hermitian circuit (e.g. a pair of coupled lossy dimers). Our results may have an impact on PT-symmetric electronic and electromagnetic systems with a variety of applications in the ultimate manipulation of electromagnetic waves, sensors, lasers, invisibility cloaks, and negative index medium.