Discovery of new scattering singularities in complex non-Hermitian systems

Jared M. Erb,[1] Nadav Shaibe,[1] Thomas M. Antonsen Jr.,[2] Tsampikos Kottos,[3] and Steven M. Anlage[1]

[1] *Maryland Quantum Materials Center, Department of Physics, University of Maryland, College Park, Maryland 20742-4111, USA*

[2] *Institute for Research in Electronics and Applied Physics, Department of Physics, University of Maryland, College Park, MD, 20742, USA*

[3] *Wave Transport in Complex Systems Lab, Physics Department, Wesleyan University, Middletown, CT, 06459, USA*

The control of wave scattering in complex non-Hermitian settings is an exciting subject – often challenging the creativity of researchers and stimulating the imagination of the public. Successful outcomes include invisibility cloaks, wavefront shaping protocols, active metasurface development, and more. At their core, these achievements rely on our ability to engineer the resonant spectrum of the underlying physical structures which is conventionally accomplished by carefully imposing geometrical and/or dynamical symmetries. In contrast, by taking active control over the boundary conditions in complex scattering environments which lack artificially-imposed geometric symmetries, we demonstrate via microwave experiments the ability to manipulate the spectrum of the scattering operator [1]. This active control empowers the creation, destruction and repositioning of exceptional point degeneracies (EPD's) in a two-dimensional (2D) parameter space [2]. The presence of EPD's signifies a coalescence of the scattering eigenmodes, which dramatically affects transport. The scattering EPD's are partitioned in domains characterized by a binary charge, as well as an integer winding number, are topologically stable in the two-dimensional parameter space, and obey winding number-conservation laws upon interactions with each other, even in cases where Lorentz reciprocity is violated; in this case the topological domains are destroyed. Ramifications of this understanding is the proposition for a unique input-magnitude and phase-insensitive 50:50 in-phase/quadrature (I/Q) power splitter. Our study establishes an important step towards complete control of scattering processes in complex non-Hermitian settings.

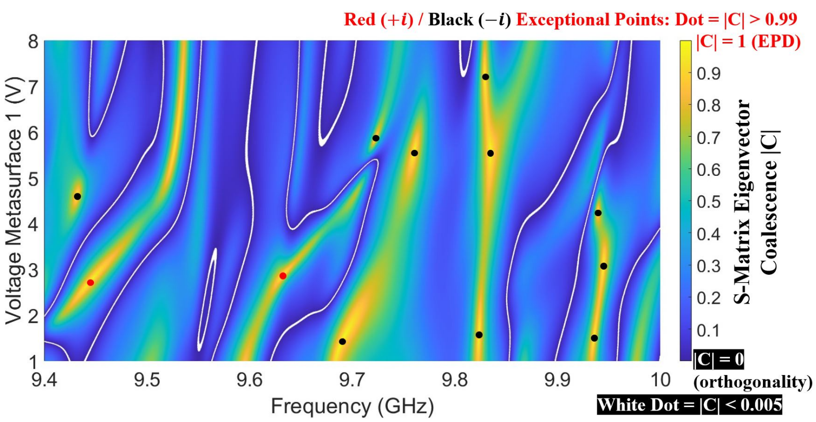

FIG. 1. Exceptional point degeneracies, orthogonality curves, and EPD domains in a two-dimensional parameter space. Experimental scattering matrix eigenvector coalescence $|C|$ vs frequency and tunable metasurface applied bias voltage in the 2-port two-dimensional rectangular microwave billiard. The red and black dots correspond to the $M_S^R = +i$ and $M_S^R = -i$ EPD's, respectively, where $M_S^R \equiv \frac{S_{11}-S_{22}}{2S_{21}}$. The extended white regions are points of near zero eigenvector coalescence ($|C| < 0.005$). The different domains hosting the two types of EPD's ($M_S^R = \pm i$) are clearly shown in this plot. The zeros of $\mathcal{I}m(M_S^R)$ form the interface between the two different domains, and also correspond to the curves of orthogonality in the eigenvector coalescence $|C|$. Each EPD type can have a ± 1 winding number, and only like-charged EPDs of opposite winding number can annihilate or be created.

Acknowledgements This work was supported by NSF/RINGS under grant No. ECCS-2148318, ONR under grant N000142312507, DARPA WARDEN under grant HR00112120021.

[1] J. Erb, D. Shrekenhamer, T. Sleasman, T. Antonsen, and S. Anlage, Control of the scattering properties of complex systems by means of tunable metasurfaces, Acta Physica Polonica A **144**, 421 (2023).

[2] J. Erb, N. Shaibe, R. Calvo, D. Lathrop, T. Antonsen, T. Kottos, and S. M. Anlage, Novel topology and manipulation of scattering singularities in complex non-Hermitian systems (2024), arXiv:2411.01069 [cond-mat.mes-hall].