Reflectionless Excitation of Arbitrary Photonic Structures: A General Theory

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Coupling an input wave into or through a scattering structure without any reflection is a ubiquitous challenge in all of wave physics, both classical and quantum. While reflectionless perfect transmission through parity symmetric 1D structures is familiar to all physicists, the conditions for reflectionless excitation of general, non-symmetric structures in multi-channel, 2D and 3D geometries have not previously been elucidated in terms of a general theoretical and computational framework. Here I will describe such a theory, which is based on general analytic properties of the scattering matrix, and applies to the linear wave equations of optics and photonics, acoustics and quantum mechanics [1,2]. It is shown that for finite resonant structures there exist a countably infinite number of complex frequencies at which such reflectionless harmonic solutions occur, which correspond to adapted input wavefronts, related to eigenvectors of a generalized reflection matrix with eigenvalue equal to zero. We refer to such discrete solutions as reflectionless scattering modes (RSMs). A special case of this is Coherent Perfect Absorption or time-reversed lasing, for which the energy is completely absorbed when the time-reverse of the analogous lasing mode is imposed on the system [3]. However in the more general theory these solutions can be fully transmitted into any specified set of output channels of a lossless structure. In order for RSMs to correspond to steady-state harmonic solutions (real frequency) either the structure must have a symmetry such as Parity-Time (PT), or one must be able to tune one parameter of the structure to achieve a real frequency RSM. Degeneracy of two RSM modes corresponds to a new kind of exceptional point (EP) and leads to an increase in the bandwidth of the perfect absorption or transmission resonance. Applications of the theory to demonstrate perfect impedance matching to non-trivial 2D photonic structures, such as chaotic waveguide junctions, will be presented, indicating its suitability and tractability for photonic design.

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