Coherent control of waves in chaotic and random systems: blind focusing on resonators and perfect absorption

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The interaction of waves with complex scattering matter (multiply scattering random materials, multimode fibers, chaotic cavities, etc.) results in a scrambling of incident radiation with a seemingly uncontrollable speckle pattern. Nonetheless, the propagation of waves can be coherently controlled by shaping the amplitude and phase of an incident wavefront in order to counteract the impact of random wave scattering [1]. For instance, the wave can be focused through random media using closed-loop iterative schemes or by relying on a measurement of the transmission matrix to extract an optimal wavefront with maximally focused intensity. In this talk, we will discuss new wavefront shaping techniques with optimal functionalities in chaotic and disordered systems. The applications span from energy harvesting, precision sensing and wave filtering to wireless communications.

In the first part, we will show that we can leverage the dwell-time enhancement of waves that interact with a resonator within a complex scattering medium to extract the incident wavefront providing optimal energy storage within the resonator [2]. Our approach is based on the time-delay Wigner-Smith operator which gives the fullest account of time delays between incident and outgoing wavefronts. The optimality of the first eigenvector for energy storage is demonstrated with a modal analysis and confirmed in *in-situ* microwave measurements. Our approach is blind and non-invasive and provides a framework for enhanced light-matter interactions in disordered systems.

The second part will be dedicated to coherent perfect absorption (CPA) which is a generalization of the critical coupling condition to systems which can involve overlapping resonances and/or multichannel excitation, and which include irreversible loss mechanisms [3]. At CPA, a zero of the system's scattering matrix lies on the real frequency axis and the incident wavefront ψ_{in} corresponding to the eigenvector associated with the zero is completely absorbed within the system without any reflection: $\psi_{out} = S\psi_{in} = 0$. CPA has been realized in systems with regular geometries and has recently been extended to disordered systems. Achieving CPA usually requires to tune two parameters: the wavelength and the absorption within the medium. Here we will show that these requirements can be lifted by endowing a chaotic cavity with reconfigurability [4]. We demonstrate 'on-demand' eight-channel CPA at an arbitrary frequency in a chaotic cavity by tweaking the scattering matrix using reconfigurable metasurfaces [5]. A theoretical analysis based on the effective Hamiltonian quantitatively explains the shape of the reflection dip associated with a CPA state. We further demonstrate that the delay time of waves within the cavity diverges at the CPA condition as a consequence of the phase singularity [5]. A CPA state hence provides an extreme sensitivity to minute perturbations at any location within the medium. Finally, we will show that the vexing need of coherent control on the incident wavefront can be overcome by including an additional constraint on the CPA wavefront in the optimization procedure to make it coincide with any imposed arbitrary wavefront [6].

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