Ideal Light Capturing by a Hermitian System

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Optical structures exhibiting a linear response are widespread in nature. Linearity implies that their response to any time-varying input can be described through the frequency dependent scattering operator (or scattering matrix), which relates the amplitudes of the outgoing and the incoming radiation channels. The scattering matrix is a complex-valued analytical function. Although for description of light scattering it is usually sufficient to know the behavior of the scattering matrix on the real frequencies axis, knowing its behavior in the complex frequency plane provides intuitive insights into the system response. In the complex frequency plane, the S-matrix has a set of singularities, which can be of two kinds: zeros and poles. The first correspond to the solutions of Maxwell equations without outgoing fields, i.e., perfectly absorbing modes, while the latter correspond to lasing modes with infinite response on an incident field driven at the complex frequency. Knowledge of these singularities allows one to calculate the scattering matrix at any frequency. In a Hermitian system, the poles and zeros of the S-matrix always exist in pairs and their position is related via complex conjugation. Specifically, poles are always located in the lower half-plane, while the zeros are located in the upper half-plane, which correspond to exponential attenuation and divergence of these modes, respectively.

Here we show that it is possible to ideally excite a scattering zero of a Hermitian system in the complex frequency plane to induce virtual absorption of light and its release from the system on demand. In order to access the complex-valued scattering zero, we shape the incident field such that its profile matches the exponentially diverging profile of the perfectly absorbing mode during a finite interval of time. During that time, the scattering from the structure totally vanishes as if the structure were perfectly absorbing. However, when the exponentially growing incident field cuts off, it gives rise to immediate release of the energy stored in the lossless system during the transient. We show that virtual absorption by these complex frequency modes enables storing the electromagnetic energy within the 1D and 2D structures for arbitrary amount of time and release of the stored energy controlled by the incident field. This result highlights the fundamental properties of Hermitian electromagnetic structures and may have relevant implications for light storing and release on demand.