Nonlinear and Short-Orbit Time-Reversal in a Wave Chaotic System

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Exploiting the time-reversal invariance and reciprocal properties of the lossless wave equation enables elegantly simple solutions to complex wave-scattering problems and is embodied in the time-reversal mirror [S. M. Anlage, J. Rodgers, S. Hemmady, J. Hart, T. M. Antonsen, E. Ott, Acta Physica Polonica A **112**, 569 (2007).]. In previous work, we extended the concepts of Loschmidt Echo and Fidelity to classical waves, such as acoustic and electromagnetic waves, to realize a new sensor paradigm [B. T. Taddese, J. Hart, T. M. Antonsen, E. Ott, and S. M. Anlage, Appl. Phys. Lett. **95**, 114103 (2009); B. T. Taddese, T. M. Antonsen, E. Ott, and S. M. Anlage, J. Appl. Phys. **108**, 114911 (2010) ; B. T. Taddese, G. Gradoni, F. Moglie, T. M Antonsen, E. Ott, S. M. Anlage, New J. Phys. **15**, 023025 (2013)]. Here we demonstrate the implementation of an electromagnetic time-reversal mirror in a wave chaotic system containing a discrete nonlinearity [M. Frazier, B. Taddese, T. Antonsen, S. M. Anlage, Phys. Rev. Lett. **110**, 063902 (2013). See "Alice and Bob Go Nonlinear" Synopsis on Physics.APS.org]. We demonstrate that the time-reversed nonlinear excitations reconstruct exclusively upon the source of the nonlinearity. As an example of its utility, we demonstrate a new form of secure communication and point out other applications.

A typical time reversal experiment requires that a transmitter be initially present at the target focusing point, which limits the application of time-reversal techniques. We propose a method to focus waves at an arbitrary location inside a complex enclosure using a numerically calculated wave signal [Bo Xiao, *et al*., http://arxiv.org/abs/1409.3850]. We use a semi-classical ray algorithm to calculate the signal that would be received at a transceiver port resulting from the injection of a short pulse at the desired target location. The quality of the reconstruction is quantified in three different ways and the values of these metrics can be predicted by the statistics of the scattering-parameter $|S21|^2$ between the transceiver and target points in the enclosure. We experimentally demonstrate the method using a flat microwave billiard and quantify the reconstruction quality as a function of enclosure loss, port coupling and other considerations.

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