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Published Online: 17 April 2018

Linear nonreciprocal transmission of sound in a viscous fluid with asymmetric scattteres

The Journal of the Acoustical Society of America **143**, 1947 (2018);
https://doi.org/10.1121/1.5036380

Arkadii Krokhin

- Phys., Univ. of North Texas, 1155 Union Circle # 311427, Denton, TX 76203, arkady@unt.edu

Ezekiel Walker

- Echonovus Inc, Denton, TX

ABSTRACT

Reciprocity theorem is hold for wave equation due to time-reversal symmetry. Dissipative losses introduced by adding imaginary part to elastic modulus make sound propagation irreversible but the reciprocity theorem remains valid. In viscous fluid acoustic oscillations of local velocity follow the Navier-Stokes equation, which is not time-reversible. However, broken T-symmetry does not necessarily lead to nonreciprocity. Here we demonstrate that the necessary condition for nonreciprocal propagation in a viscous fluid is broken P-symmetry, which can be achieved by introducing asymmetric scatterers in a viscous environment. The experiment was done with a phononic crystal of Al rods in water. The rods have asymmetric cross-section in

a form of a circular sector with an arc of 120 degrees. The measured transmission spectrum exhibits signatures of nonreciprocity within a range of frequencies from 300 to 450 kHz. The experimental results are in agreement with numerical simulations based on the linearized Navier-Stokes equation. The nonrecipocity is due to different viscous losses accumulated along sound propagation in two opposite directions with broken P-symmetry. Nonreciprocity increases for the rods with more rough surfaces since dissipation occurs mainly in a viscous boundary layer of thickness of few microns. Unlike previously proposed nonreciprocal devices based on nonlinearity or local spinning of fluid, our passive device is small, cheap, and does not require energy source. [Work supported by the NSF under Grant No. 1741677.]