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Time Reversal of Acoustic Waves in the Nonlinear Regime: Basic Physics and Application to Ultrasound Contrast Imaging

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Time reversal invariance of acoustic waves propagation remains valid even in the nonlinear regime in non dissipative media. This very interesting property that was extensively used in linear acoustics can also find potential applications in the nonlinear regime. Harmonic imaging coupled to the use of contrast agents is a topic of wide interest in ultrasonic medical imaging. Images are built at twice the excitation frequency that corresponds to the resonance frequency of the bubbles embedded in the medium. Consequently, the contrast becomes important between areas of low and high concentration of bubbles. However, at a high mechanical index, the harmonic components of backscattered echoes depends on the intrinsic nonlinear properties of tissues as well as the bubble's resonance. The focused beam is generating harmonics during its nonlinear propagation. It results in a degradation of the harmonic image contrast. Time reversal is an elegant way to find the emission codes allowing us to cancel the harmonic components due to nonlinear propagation of the ultrasonic beam. In the absence of bubbles, if the backscattered echoes are time-reversed and reemitted by the array, the harmonic components of the resulting wavefront are transferred back to the fundamental frequency during propagation. Experiments conducted with 1D-linear arrays illustrate these cancellation techniques.