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Hidden acoustic information revealed by intentional nonlinearity[1]

DAVID R. DOWLING, Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109-2133

Acoustic waves are omnipresent in modern life and are well described by the linearized equations of fluid dynamics. Once generated, acoustic waves carry and collect information about their source and the environment through which they propagate, respectively, and this information may be retrieved by analyzing recordings of these waves. Because of this, acoustics is the primary means for observation, surveillance, reconnaissance, and remote sensing in otherwise opaque environments, such as the Earth's oceans and crust, and the interior of the human body. For such information-retrieval tasks, acoustic fields are nearly always interrogated within their recorded frequency range or bandwidth. However, this frequency-range restriction is not general; acoustic fields may also carry (hidden) information at frequencies outside their bandwidth. Although such a claim may seem counter intuitive, hidden acoustic-field information can be revealed by re-introducing a marquee trait of fluid dynamics: nonlinearity. In particular, an intentional quadratic nonlinearity – a form of intra-signal heterodyning – can be used to obtain acoustic field information at frequencies outside a recorded acoustic field's bandwidth. This quadratic nonlinearity enables a variety of acoustic remote sensing applications that were long thought to be impossible. In particular, it allows the detrimental effects of sparse recordings and random scattering to be suppressed when the original acoustic field has sufficient bandwidth. In this presentation, the topic is developed heuristically, with a just brief exposition of the relevant mathematics. Hidden acoustic field information is then revealed from simulated and measured acoustic fields in simple and complicated acoustic environments involving frequencies from a few Hertz to more than 100 kHz, and propagation distances from tens of centimeters to hundreds of kilometers.

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