

A 3D-Printed Monolithic Bender Bar Transducer Featuring a Fluid-coupled Thin-plate Backing and Flexural Hinges

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Summary:

A 3D-printed monolithic bender bar transducer featuring a thin-plate backing and flexural hinges is proposed to overcome the acoustic short circuit effect in low frequency underwater applications. Fabricated via powder bed fusion, this structure creates a narrow fluid gap that strongly couples with the thin plate, functioning as an effective dynamic boundary. Experimental results demonstrate that this compact design transforms the dipole radiation into an omnidirectional monopole pattern, significantly increasing acoustic radiation efficiency while offering a tunable acousto-structural framework for future applications.

Keywords: bender bar transducer, 3D printing, pressure release, dynamic boundary, acousto-structural coupling

Background, Motivation and Objective

Bender-type transducers are widely utilized for low-frequency underwater acoustic projectors due to their high-power output and compact size [1]. However, when operating in a free-field environment without backing structures, they act as dipole sources. At low frequencies, the out-of-phase radiation from the front and rear faces causes a severe acoustic short-circuit, which drastically reduces the radiation resistance and overall transmitting efficiency. Conventional approaches to prevent this issue rely on thick, heavy metal housings with air-backing or elastomeric backing materials, such as Corprene, to block rearward acoustic radiation and provide pressure release [2, 3]. While effective, these conventional methods significantly increase the volume and weight of the sonar system and limit the operational bandwidth. Therefore, the objective of this work is to introduce a novel, highly compact monolithic bender bar transducer utilizing a 3D-printed thin plate dynamic boundary.

We investigate the strong acousto-structural coupling mediated by a narrow fluid gap to achieve an effective pressure release condition of bender bar transducers without the bulk of conventional housings. We aim to demonstrate, through both finite element method (FEM) models and empirical lake tests, that the bender bar with thin-plate backing behaves to a pressure release condition, thereby maximizing acoustic output and transforming the dipole radiation into an omnidirectional monopole pattern.

Description of the New Method

The proposed transducer features a completely monolithic titanium mechanical body driven by a [011] poled Mn:PIN-PMN-PT piezoelectric single crystals which provide superior 32 piezoelectric properties for bending mode [4].

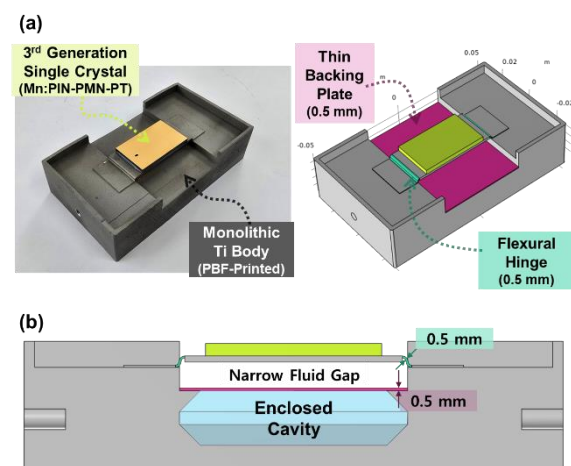


Fig. 1. Structure of the monolithic bender bar transducer (a) Photograph of the fabricated titanium prototype via powder bed fusion (PBF) incorporating the Mn:PIN-PMN-PT single crystal. (b) Cross-sectional view, detailing the 0.5 mm-thick flexural hinges, the narrow fluid gap, and the thin plate for dynamic boundary.

Unlike traditional assembled transducers, this entire titanium structure — encompassing the bender, flexural hinges, and thin-plate backing — is manufactured as a single entity using Powder Bed Fusion (PBF) 3D printing technology.

This ultra-precise fabrication enables the integration of a 0.5 mm-thick flexural hinge to realize a simply supported boundary condition at both ends of the bender bar, alongside a 0.5 mm thin metal plate positioned closely behind the bender bar to encapsulate an air cavity. Traditional machining cannot fabricate such a seamless, fully enclosed acoustic cavity without introducing mechanical losses at assembly joints. Thus, PBF 3D printing is a fundamental prerequisite for realizing the flexural hinges and dynamic boundary conditions in a physical prototype.

In our transducer design, a narrow fluid gap (approximately 5 mm) exists between the bender and the thin-plate backing. This fluid layer induces a strong acousto-structural coupling between the two components. Acoustically, this resonant thin-plate backing acts as an engineered dynamic boundary. The acoustic response is not merely dictated by the air volume, but is fundamentally governed by the engineered structural compliance of this PBF-printed thin-plate backing. At low frequencies, the plate's precise flexibility yields to the acoustic pressure through this coupling medium, effectively absorbing the rearward radiation and acting as an efficient pressure release boundary.

Results

The FEM simulations and subsequent lake tests rigorously validated the acoustic mechanism of the engineered dynamic boundary. FEM simulations were established comparing three conditions: a bare bender, a bender with an ideal pressure release (PR) boundary at the rear, and a bender with the proposed thin-plate backing. To provide a clear comparative analysis, the frequency axis was normalized to the primary resonance of the proposed model (f_0).

As shown in Fig. 2, the bare bender exhibited a typical dipole beam pattern with severe acoustic cancellation. Conversely, the proposed model revealed that the strong coupling between the bender and the thin plate mirrors the pressure release boundary around $1.0f_0$. This interaction successfully decoupled the rearward radiation, generating an omnidirectional monopole pattern. Notably, the dynamic boundary also induced an additional low-frequency resonance mode at approximately $0.44f_0$. This unique characteristic, absent in both bare and ideal PR models, demonstrates the profound influence of the acousto-structural coupling on the system's dynamic response. Consequently, by effectively eliminating the acoustic short-circuit, the radiation resistance was fully recovered. The lake test results confirmed these theoretical predictions; the measured transmitting voltage response (TVR) of the proposed design was substantially enhanced compared to the bare bender model,

matching the acoustic performance of an ideal PR boundary while maintaining an extremely thin, monolithic profile.

Furthermore, this coupled fluid-structure system establish a versatile foundation for tuning resonance behaviors in future advanced transducer designs.

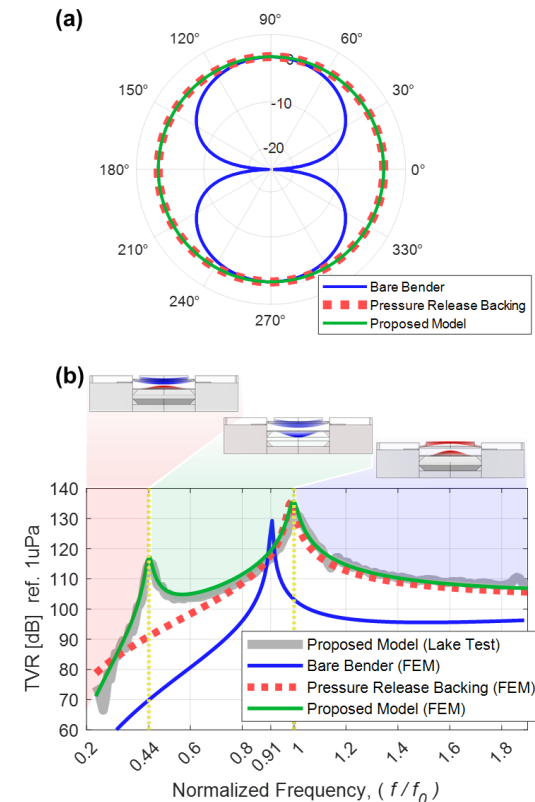


Fig. 2. Acoustic performance validation. (a) Simulated (FEM) beam patterns comparing the bare bender (dipole) to both an ideal pressure release (PR) condition and the proposed model (monopole). (b) Transmitting voltage response (TVR) illustrating the theoretical FEM comparisons and the empirical lake test results of the proposed transducer, demonstrating the elimination of the acoustic short-circuit and pressure enhancement due to the dynamic boundary.

References

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