proceedings

Abstract

Efficient Modeling of Piezoelectric Micromachined Ultrasonic Transducers Using a Combination of Finite and Lumped Element Modeling †

Romain Liechti *, Francois Blard, Jean-Rémi Chatroux, Jean-Claude Bastien, Hélène Lhermet and Bruno Fain

CEA-Leti, University Grenoble Alpes, F-38000 Grenoble, France; francois.blard@cea.fr (F.B.); jean-remi.chatroux@cea.fr (J.-R.C.); jeanclaude.bastien@cea.fr (J.-C.B.); helene.lhermet@cea.fr (H.L.); bruno.fain@cea.fr (B.F.)

* Correspondence: romain.liechti@cea.fr

† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: This research paper presents a comprehensive methodology for the efficient modeling of piezoelectric micromachined ultrasonic transducers (PMUTs) using a combination of finite and lumped element models. A single membrane is first studied in air with an eigenfrequency study in order to calibrate the lumped element model on the finite element model. From this electrical equivalent circuit, a complete model of the PMUT cell composed of numerous membranes is developed using the propagation, directivity, absorption, mutual and self-impedances, and variability of the resonance frequencies due to manufacturing discrepancies. The calculated acoustic response of the PMUT is then compared with a measured response, in water. The relatively good agreement between the simulation and the measurement, as well as the very low computation time, makes this approach relevant for further optimization of the PMUT design to target larger bandwidth and higher sensitivity.

Keywords: PMUT; LEM; FEM

Citation: Liechti, R.; Blard, F.; Chatroux, J.-R.; Bastien, J.-C.; Lhermet, H.; Fain, B. Efficient Modeling of Piezoelectric Micromachined Ultrasonic Transducers Using a Combination of Finite and Lumped Element Modeling. *Proceedings* **2024**, 97, 60. https://doi.org/10.3390/proceedings2024097060

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 20 March 2024

1. Introduction

Accurate simulation of piezoelectric micromachined ultrasonic transducers (PMUTs) is decisive for the optimization of their performance without building expensive prototypes. Finite element simulation is widely used but is quickly limited by computation time when simulating large arrays of transducers. To circumvent this limitation, we propose to calibrate a lumped element model of a single membrane on a 2D axisymmetric finite element model and to use the latter in a complete analytical model to predict the frequency response of a PMUT cell in liquid medium The PMUT cell encompasses three columns of 76 membranes each for a total size of 190×5000 µm^2.

2. Materials and Methods

2.1. Single Transducer in Air

The model first focuses on the simulation of a single diaphragm. The membrane radius is 26.5 µm. The stack is composed of 100 nm SiO_2/1500 nm Si/200 nm Mo/900 nm AlN/200 nm AlCu/300 nm SiN. An equivalent circuit of a single diaphragm is derived using the approach presented in [1]. The imperfect anker stiffness is adjusted to match the finite element model.

2.2. PMUT Cell

Then, the variability of the resonance frequency is included as a truncated normal distribution of the compliance within an assembly of transducers (Figure 1a) to account for the manufacturing discrepancies across a cell. From this model, the electrical impedance of a cell in air is calculated and compared with the measured value, reflecting the Q factor of 7 observed experimentally (Figure 1b).

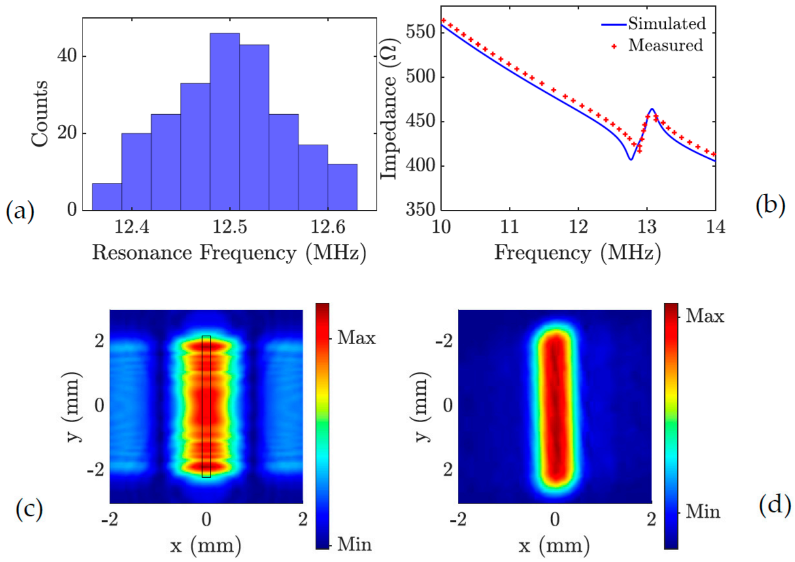

Figure 1. Distribution of the resonance frequencies of the 228 transducers of one cell calculated using a truncated normal distribution with a maximum deviation of 3% from the nominal value (**a**), simulation and measurement of the electrical impedance of a cell (**b**), acoustic pressure of a cell simulated by the analytical model in a plane parallel to the plane of the PMUT at a distance of 2.11 mm, (**c**) and the corresponding acoustic pressure measured in water (**d**).

The mechanical impedance of a cell in water is then calculated, considering the self and mutual radiation impedances [2]. A comprehensive equivalent lumped model is built (not shown). From the total mechanical impedance and the transfer function of the electrical part of the equivalent circuit, the pressure radiated at a specific point in space can be calculated, using the monopole approximation, the absorption from the media, and the directivity index. The calculated pressure field on a plane parallel to the PMUT (Figure 1c) can then be compared with the measured value in the same conditions (Figure 1d). The good agreement between the simulated and measured electrical, mechanical, and acoustical characteristics demonstrates that this approach is meaningful to optimize the design for a higher sensitivity or a broader bandwidth.

Author Contributions: Conceptualization, B.F. and R.L.; Methodology, B.F. and R.L.; Software, R.L.; Visualization R.L. and F.B.; Investigation, F.B.; Project Administration H.L. and B.F.; Writing—original draft, R.L.; Writing—review and editing, B.F.; Resources, J.-C.B., J.-R.C. and F.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study has been funded by ECSEL Joint Undertaking project POSITION-2. The authors also thank SOITEC for their support.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Pala, S.; Lin, L. An Improved Lumped Element Model for Circular-Shape PMUTs. *IEEE Open J. Ultrason. Ferroelectr. Freq. Control* **2022**, *2*, 83–95. [CrossRef]
2. Oguz, H.K.; Atalar, A.; Koymen, H. Equivalent Circuit-Based Analysis of CMUT Cell Dynamics in Arrays. *IEEE Open J. Ultrason. Ferroelectr. Freq. Control* **2013**, *60*, 1016–1024. [CrossRef] [PubMed]