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Modeling and Optimization Methods of an Electrostatically driven MEMS Speaker

DISSERTATION

To obtain the Academic Degree

Doctor of Technical Sciences

Vienna University of Technology

Institute of Mechanics and Mechatronics

Measurement and Actuator Division

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Janurary/2014

Measurement-, Actuator-, and Simulation-Technology

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Modeling and Optimization Methods of an Electrostatically driven MEMS Speaker

Shaker Verlag
Aachen 2014

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Wien, TU, Diss., 2014

Printed in Germany.

ISBN 978-3-8440-2697-9
ISSN 2195-0288

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgements

I would like to thank my thesis advisor Univ.-Prof. Dr. techn. Dr.-Ing. Habil Manfred Kaltenbacher for his continuous help and assistance.

I also want to express my thanks to all colleagues at the **Vienna University of Technology** at the **department of Mechanics and Mechatronics** for their great support while working on my thesis. Particularly, I want to thank Klaus Bergkirchner, Paul Finsterwalder and Manfred Neumann for their inputs and help during the development process of the demonstrator hardware. Andreas Hüppe, Stefan Zörner and Hendrik Husstedt for their contributions finding new solving strategies and result interpretations. Dominik Perchtold for his great support in MATLAB. Till Knifka for his expertise in solid mechanics and modal analysis. Many thanks also to all namely not mentioned colleagues for their great time, the pleasant working atmosphere and their contribution to the work. I also appreciate Alfons Dehé, Mohsin Navaz and Christoph Glacer for their industrial support and teamwork at Infineon Munich, as well as Andreas Kenda and Martin Lenzhofer from CTR AG in Villach.

I also want to thank my family for their unconditional support, at any time and any place.

Finally, I would like to thank everybody who was important to the successful realization of this thesis, as well as expressing my apology that I could not mention personally one by one.

"The task is...not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees."

Erwin Schrödinger
1887 - 1961

This project has been supported within the COMET - Competence Centers for Excellent Technologies Programs by BMVIT, MBWFJ and the federal provinces of Carinthia and Styria.

Abstract

The market for battery powered devices, such as smart-phones or tablets increases rapidly. The trend goes towards smaller and thinner cases. The main challenge is to decrease the power consumption by coincidently shrinking the device size and increasing the efficiency. Micro-electro-mechanical-systems (MEMS) manufactured of silicon, merge cost effective and space saving features as an energy efficient and innovative product. In this work, reversible operated silicon microphones are modeled and optimized towards sound pressure level and total harmonic distortion. The models are described by coupled partial differential equations and solved by the help of the finite element method. Due to the small dimensions of a single acoustic transducer of approximately one millimeter in diameter and two micrometer in thickness, the loudspeaker is manufactured as an eight bit array. The array arrangement opens up the opportunity to drive the speaker in conventional analog driving mode or apply digital sound reconstruction. Geometric nonlinearities such as large deformation, pre-stress or mechanical contact are reflected in the mechanical model and excited electrostatically. By applying the virtual displacement method, the influence of the insulation layer is mapped to the electrostatic force computation. The electrostatic force interacts with the structural mechanics and the membrane starts to oscillate. The electrostatically actuated membrane is coupled to the acoustic model, where the sound pressure level is computed. The challenge in the acoustic propagation computation is on the one hand, the number of unknowns, which can be minimized by using Mortar FEM (non-conforming grids), and on the other hand, in the reflections caused by the bounds of truncating the propagation region. These reflections are minimized with absorbing boundary conditions or a perfectly matched layer surrounding the propagation region. Acoustic results on the single transducer were computed by the finite element method, where for the full speaker array a specially developed wave field computation software was used based on the Kirchhoff-Helmholtz integral. In addition, two optimization strategies towards increasing the sound pressure level were presented. The first deals with stress-induced self raising of the back plate structure, to increase the volume flow and sound pressure level. The second deals with the digital sound reconstruction, investigating the non-reset, with-reset and latched method.

Kurzfassung

Der Markt an Batterie betriebenen Geräten wie Smartphones oder Tabletts nimmt stark zu. Der Trend geht immer mehr in Richtung schlanker und dünner Gehäuse. Um die Laufzeit dieser Geräte bei gleichbleibender, oder sogar schlankerer, Gehäuseform zu verlängern, ist es wichtig energieeffiziente Bauteile zu verbauen. Silizium gefertigte mikro-elektro-mechanische Systeme (MEMS) verbinden kostengünstige und platzsparende Eigenschaften als energieeffizientes und innovatives Produkt. In dieser Arbeit werden reversibel betriebene Silizium-Mikrophone modelliert und hinsichtlich Schalldruckpegel und Signalqualität optimiert. Die Modelle werden mit Hilfe von gekoppelten partiellen Differentialgleichungen beschrieben und mit der Methode der Finiten Elemente gelöst. Auf Grund der geringen Dimensionen eines Einzelwandlers von zirka einem Millimeter Durchmesser und zwei Mikrometer dicke, werden die Lautsprecher in einem acht Bit Array betrieben. Der Array-Betrieb ermöglicht zusätzlich neben analogen Betriebsmoden, auch Untersuchungen der digitalen Schall-Rekonstruktion. Geometrische Nichtlinearitäten, wie große Verformung, Vorspannungen oder mechanischer Kontakt werden im mechanischen Model abgebildet und elektrostatisch angeregt. Mit Hilfe der virtuellen Verschiebung wird der Einfluss von Isolationsschichten auf den elektrostatischen Kraftbeitrag abgebildet. Die elektrostatisch angeregte Membran resultiert in einer mechanischen Bewegung und koppelt in ein akustisches Model. Die Herausforderung im akustischen Ausbreitungsgebiet liegt einerseits in der Anzahl der Unbekannten, welche durch Anwendung von Mortar FEM (nichtkonforme Gitter) minimiert werden können, und andererseits in den Reflexionen an den Randbereichen der Ausbreitungsregion. Diese Reflexionen werden mit absorbierenden Randbedingungen oder einem zusätzlichem Gebiet mit dämpfenden Eigenschaften minimiert. Für akustische Berechnungen am Einzelwandler, werden die Finite Elemente Methode angewendet, wobei für akustische Berechnungen des gesamten acht Bit Arrays wird ein eigens entwickeltes Wellen-Feld-Berechnungs-Tool, basierend auf dem Kirchhoff-Helmholtz Integral angewendet. Zusätzlich werden zwei Optimierungsstrategien vorgestellt. Die Erste beschäftigt sich mit Stress induzierten Buckeln der Gegenelektrode, was eine flache kostengünstige Fertigung ermöglicht und gleichzeitig den Schalldruck optimiert. Die Zweite beschäftigt sich mit der digitalen Schallerzeugung.

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