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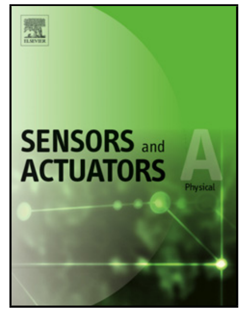

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Author: David Tumpold Matthias Stark Nikolaus Euler-Rolle Manfred Kaltenbacher Stefan Jakubek

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Linearizing an electrostatically driven MEMS speaker by applying pre-distortion

David Tumpold[a,*], Matthias Stark[b], Nikolaus Euler-Rolle[b], Manfred Kaltenbacher[a], Stefan Jakubek[b]

[a] *Institute of Mechanics and Mechatronics, Vienna University of Technology, Getreidemarkt 9/E325/A4, 1060 Vienna, Austria*
[b] *Christian Doppler Laboratory for Model Based Calibration Methodologies, Institute of Mechanics and Mechatronics, Vienna University of Technology, Getreidemarkt 9/E325/A5, 1060 Vienna, Austria*

Abstract

The market for tablets, laptops and mobile devices is increasing rapidly. Product designs trend to thinner housings at concurrently higher energy consumption, which plays a major role for battery-powered devices. Microelectromechanical (MEMS) speakers, fabricated in complementary metal oxide semiconductor (CMOS) compatible technology, merge energy efficient driving technology with cost economical fabrication processes. A recently developed finite element (FE) model for the precise computation of the non-linear MEMS speaker is presented. In addition, dynamic linearization is achieved by applying feedback linearization to the local model network (LMN) as a data-driven dynamic model of the MEMS speaker to obtain a dynamic feedforward control (FFC) for pre-distortion. In the FE model, we fully take into account geometric non-linearity, contact in the snap-in mode, non-linear electrostatic coupling forces as well as the moving of charged thin membrane-plate structures (electrodes) in an electric field. Furthermore, since we concentrate on MEMS loudspeaker applications, quality of sound plays a major role, where an undistorted and linear system defines the challenge. In the process of MEMS speaker design, both, the FE model and the FFC using LMN, can be used to optimize the MEMS speaker towards sound pressure level (SPL) and total harmonic distortion (THD).

Keywords: electrostatically driven MEMS speaker; finite element modelling; electrostatic non-linearities; feedforward control; feedback linearization; local model network

1. Introduction

In the field of MEMS speakers a differentiation between in ear applications and free field applications can be done. Requirements of in ear applications are focused on low total harmonic distortion (THD) with coincidentally small physical dimensions and low energy consumption, while free field applications are designed to obtain high sound pressure levels allowing larger surface areas. Conventional free field applications are mostly based on the electro-dynamically driving principle [1, 2], followed by piezoelectric actuators [3, 4] on second place. Electrostatically driven MEMS speakers come at the last [5, 6], because of their non-linear behaviour. A detailed comparison between our MEMS speaker and state of the art MEMS speaker systems, referring to their driving principle, field of application and membrane shape is given in [7, 8]. Although electrostatically actuated MEMS speakers have a non-linear response, they merge energy-efficient driving technology with cost-effective fabrication processes, hence they are interesting for integrated solutions. Nevertheless, MEMS prototyping is a lengthy and costly task, therefore computer aided design optimization is required. The physical interaction between the electrostatic, mechanical and acoustic field is described by coupled partial differential equations (PDE) and solved with the finite element (FE) method. As a result, all necessary non-linearities are taken into account and can be investigated and furthermore linearized by the help of pre-distortion. In this paper we investigate a MEMS speaker consisting of two circular shaped electrodes with a two micrometer air gap between them, where the layout can be compared to the inverse-operated E2120M silicon microphone of Infineon Technologies AG. Due to symmetric setup, we modelled the MEMS speaker as axis-symmetric plate type capacitor as depicted in Fig. 1 schematically. The top electrode represents the back-plate or stator and consists of a 600 nm polysilicon (poly) conductor coated with a 140 nm silicon nitride (Si_3N_4) insulation layer. The back-plate is perforated, to reduce squeeze film damping and therefore improve dynamical response (see Fig. 7). The bottom electrode is represented by a 330 nm polysilicon membrane. Because of the high intrinsic tensile pre-stress of the back-plate of about 1 GPa compared to the intrinsic tensile pre-stress of the membrane with about 43 MPa, the back-plate can be assumed as stiff and the membrane as flexible. Detailed derivations and procedures to find the correct material parameters can be found in [9], where our device is handled as microphone. Further details about the full FE model can be found in [7] and an axis-symmetric drawing

*Corresponding author
Email address: david.tumpold@tuwien.ac.at (David Tumpold)