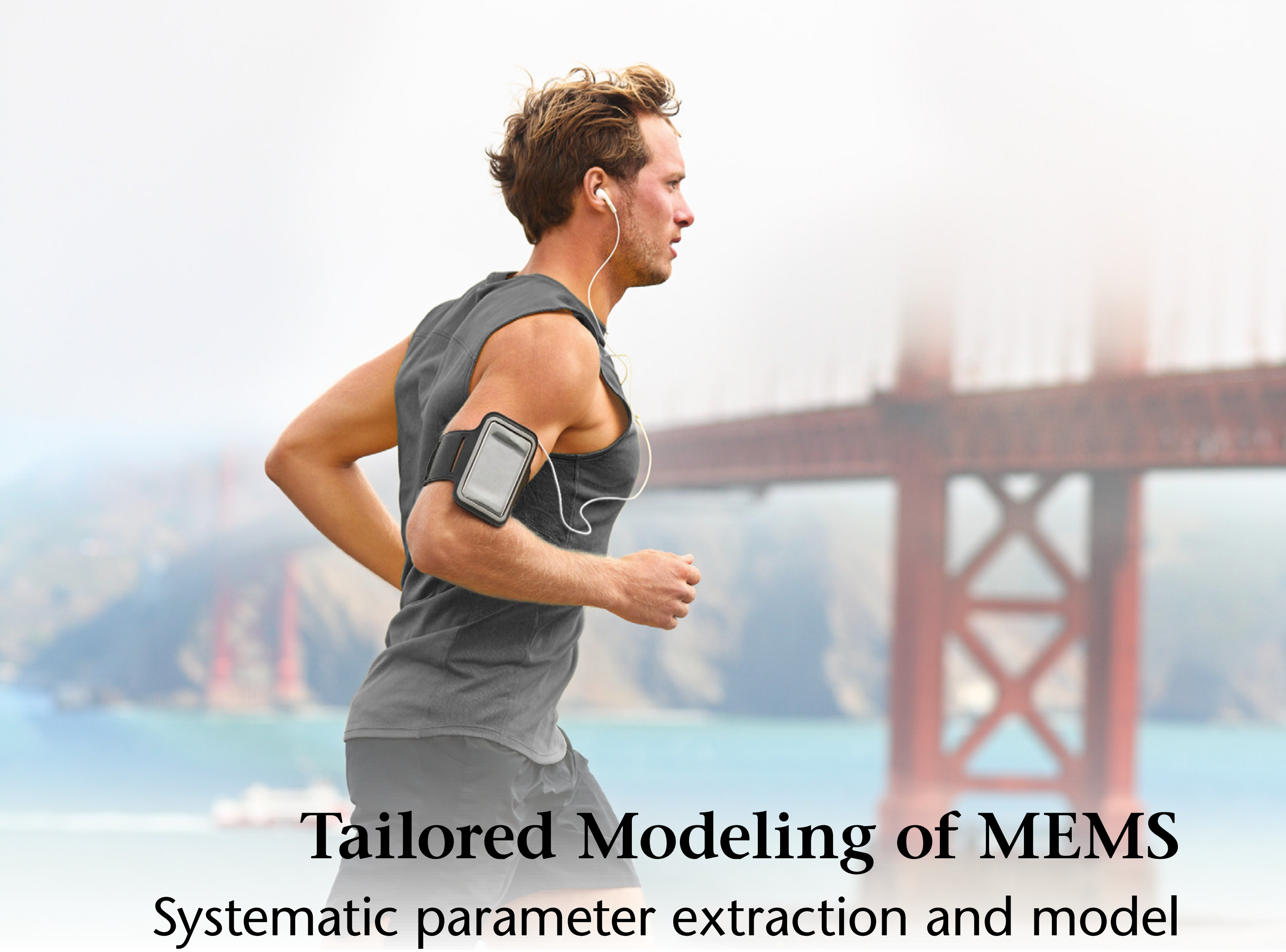


Tailored Modeling of MEMS

Systematic parameter extraction and model validation using laser Doppler vibrometry

MEMS transducers are employed in many everyday objects from tire pressure sensors to mobile phones. For optimal performance and cost savings, their complexity requires a combination of dedicated modeling and simulation procedures (virtual prototyping), together with experimental characterization, parameter extraction and model validation. ►

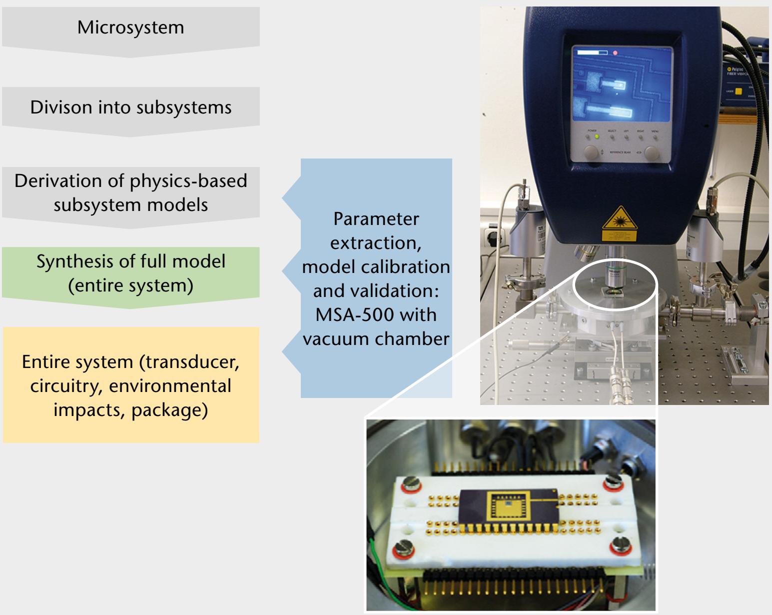


Figure 1: Hierarchical modeling approach for microelectromechanical devices and systems; parameter extraction, calibration and model validation are carried out by an MSA-500 Laser Doppler Vibrometer, which can be combined with a vacuum chamber.

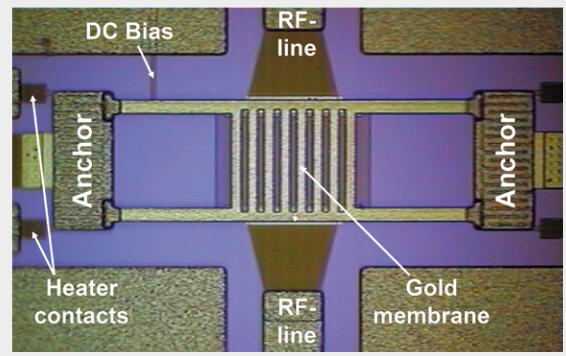


Figure 2: Micromechanical RF switch. The switch, and therefore the underlying RF signal path, can be closed by electrostatic actuation of the sliced, hinged membrane.

Although MEMS are complex, the computational expense can often be held in an acceptable range by applying reduced order models. We apply the hierarchical and modular modeling approach depicted by the flow chart in Figure 1. Here, the system is divided into subsystems, for which we derive dedicated physical submodels tailored to specific needs and practicalities. They can be implemented into a system simulator by coding them in one of the standardized hardware design languages, enabling the co-simulation of the transducer and electronic circuitry within a homogeneous environment.

One prerequisite for successful, simulation-based design is a dedicated parameter extraction, model calibration and validation strategy. To achieve this we use the experimental set-up also shown in Figure 1. It comprises an MSA-500 Laser Doppler Vibrometer, which can be combined with a vacuum chamber to enable pressure- and temperature-dependent device characterization. A white light interferometer is used to determine structural topography along with supplemental measurement equipment for electrical characterization.

Figure 3 illustrates the typical model calibration and validation procedure for an RF-MEMS switch (Figure 2). The switch comprises a sliced membrane hinged by four beams, which can be actuated electrostatically to complete an RF signal path. Initially, the mechanical submodel has to be calibrated. White light interferometric and eigenfrequency measurements deliver the required parameters such as geometrical dimensions, mechanical stiffness and deformation caused by fabrication-induced intrinsic stress (Figures 3a, 3b). The gap height under the membrane, and switching voltage can be extracted from quasistatic measurements of the electrostatically

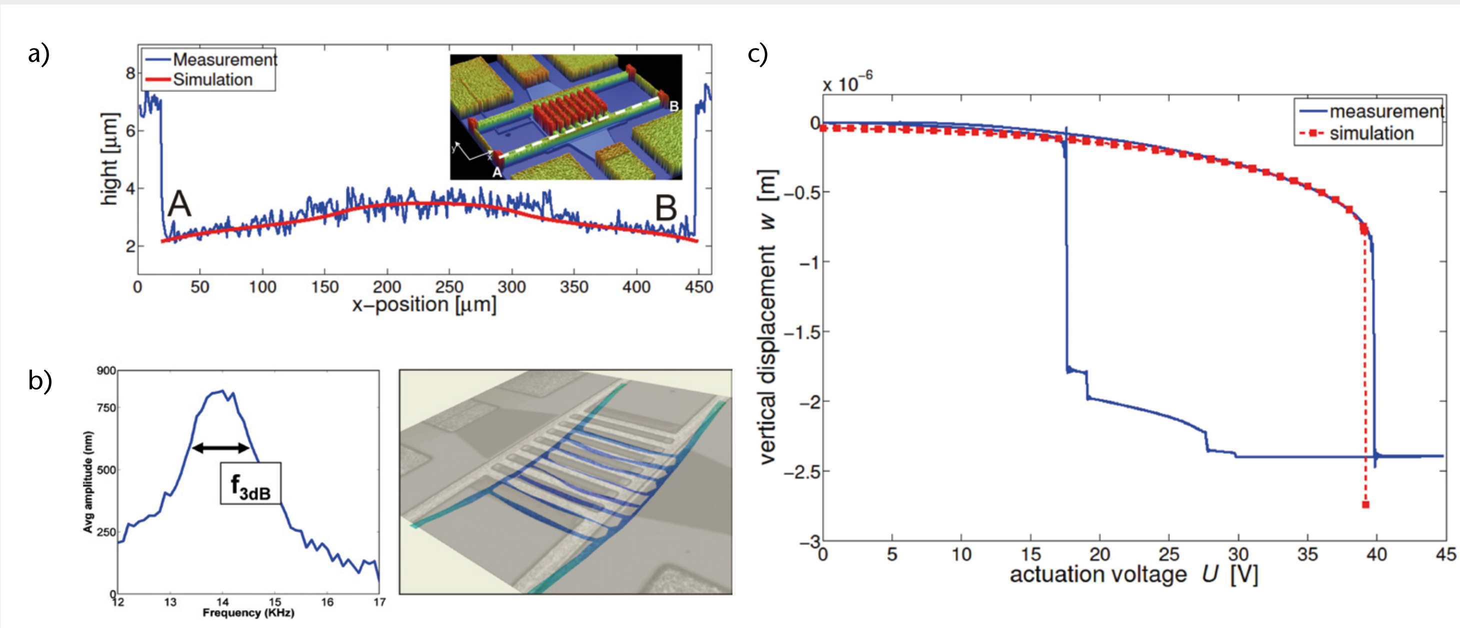


Figure 3: Exemplary data from the parameter extraction and calibration procedure of an energy-coupled simulation model of an RF-MEMS switch.
a) Initial deformation caused by intrinsic stress obtained by white light interferometry.
b) Eigenfrequency and
c) quasistatic pull-in characteristics of the bridge, both determined by laser Doppler vibrometry.

displaced membrane ("pull-in characteristics", Figure 3c). Finally, the entire model including air damping can be validated by recording the dynamic movement of the bridge. Good agreement between simulated and measured data then proves the consistency, accuracy and validity of the model, which is now ready to be used for detailed investigations of the device operation and design tasks, such as switching time optimization, switching cycles and mechanical contact forces of different design variants (Figure 4).

Figure 5 shows the membrane displacement of an alternative switch design. In order to improve its robustness during operation, meander-shaped heaters are integrated underneath the anchor regions. In case of stiction, they are activated by heating the bridge, exerting shear forces that are supposed to break up the sticking contact. Results obtained from simulation and characterization allow us to investigate the efficiency and dynamics of this concept and draw conclusions on possible improvements.

The last example, depicted in Figure 6, deals with investigating the development of novel nano-electromechanical resonators, where the gap height underneath the movable structure lies in the submicron range. For such devices, the quality factor is of great interest. Pressure-dependent Q-factors are shown, extracted from the 3dB-bandwidth of the fundamental eigenfrequency. The challenge when simulating structures with such small feature sizes is that the limits of classical continuum theory are already reached at room pressure, which has to be carefully taken into account inside the models. ■

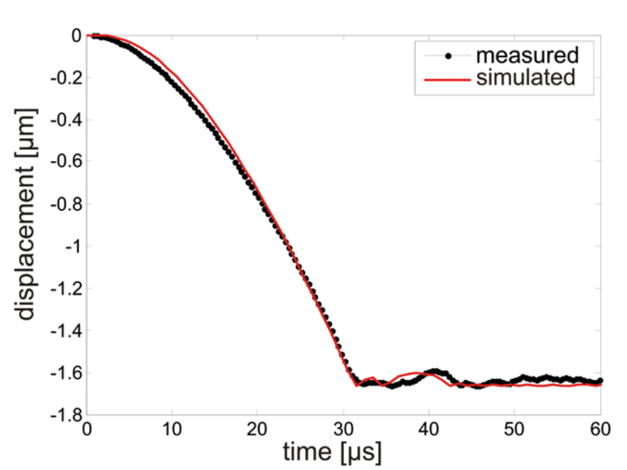


Figure 4: Closing of an RF-MEMS switch. Comparison between simulation and measurement.

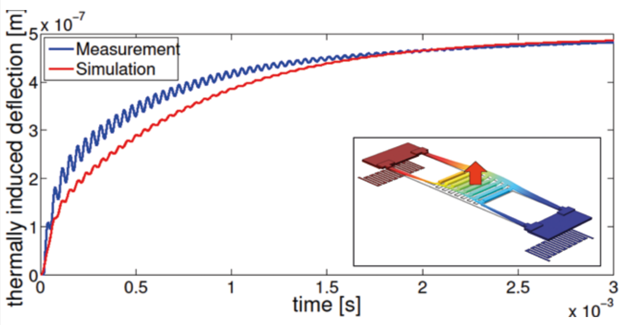
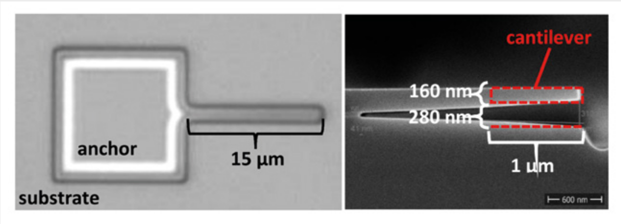


Figure 5: Transient vertical deflection of an RF-MEMS switch induced by heating the bridge. Overlayed are oscillations of the bridge in its fundamental mechanical eigenmode.



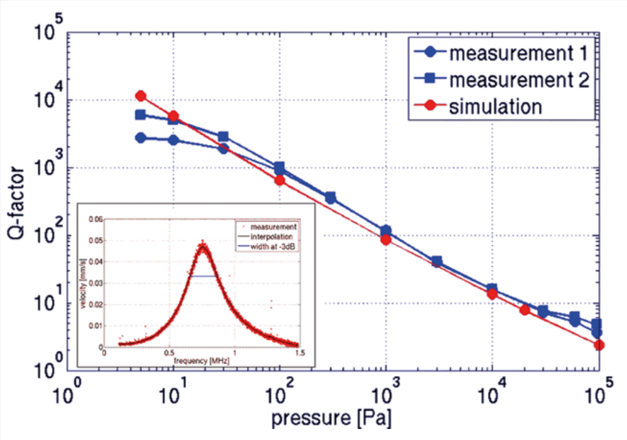


Figure 6: Micromechanical beam with a gap distance to the substrate in the sub-micron range. Pressure-dependent quality factor extracted from the 3dB-bandwith of the fundamental eigenfrequency.

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