# Design of Complex Sensor-Actuator-Systems (EKOSAS)

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The goal of the project EKOSAS is to develop methods and tools for modeling and simulation of Micro-Electro-Mechanical-Systems (MEMS). Essential points are the coupling of different physical domains to the electronic circuitry in static and dynamic case. The design environment covers T-CAD for process simulations, FEM\BEM for coupled fields on the component level and VHDL-AMS for system level simulations. Finally, these methods shall be tested and optimized on a set of complex sensor-actuator-systems. In particular, the goals are:

- Development of tools for computer aided generation of reduced order macromodels for MEMS
- Development of interfaces for data exchange between etching simulation tool (SIMODE) and FEM (ANSYS) \BEM (CAPA) simulation tools.
- Integration of all submodels in one model for system simulations
- Benchmark tests (micromirror array, ultrasonic transmitters and receivers, position sensor, inclination sensor)

**The subprojects of the Chemnitz University of Technology are focused on the automatic generation of reduced order macromodels for system simulations:**

The finite element and boundary element methods have been successfully applied to the design of micro-electro-mechanical devices on the physical level of abstraction. Comprehensive algorithms enable one to get a precise behavioural description of each single component (mechanical, thermal, electrostatic, fluidic etc.) including some of their most important interactions. Those methods are very accurate and helpful to study complicated problems but in practice they are difficult to handle and much too cumbersome for daily design tasks. Moreover, if one tries to perform system simulations or wants to consider electronic circuitry, e.g. control and evaluating electronics, finite or boundary element models are inappropriate. At present time, micro components are widely described by analytical approaches to allow a system simulation but require important simplifications of the models. Therefore, novel simulation techniques are needed. Reduced-order models also known as macromodels are a very promising alternative for fast transient and system level simulations of MEMS.

One approach that will be used in this project is well known for linear mechanical systems as Method of Modal Superposition, where the eigenmodes are used as shape functions to describe the general problem. A micromirror shown in Fig.1 is used to demonstrate the practical suitability of reduced-order models for system simulations. A computational challenge exposes since the mirror plate itself can't be considered as rigid. Stress and electrostatic stiffening are relevant and electrostatic fringing fields are essential. As a matter-of-fact the Method of Modal Superposition can be extended to nonlinear and non-mechanical systems as well. Energy methods like Lagrange's principle appear opportune to establish the equation of motion since energy is independent of the physical meaning. In static and dynamic case one needs to know just two energy functions,

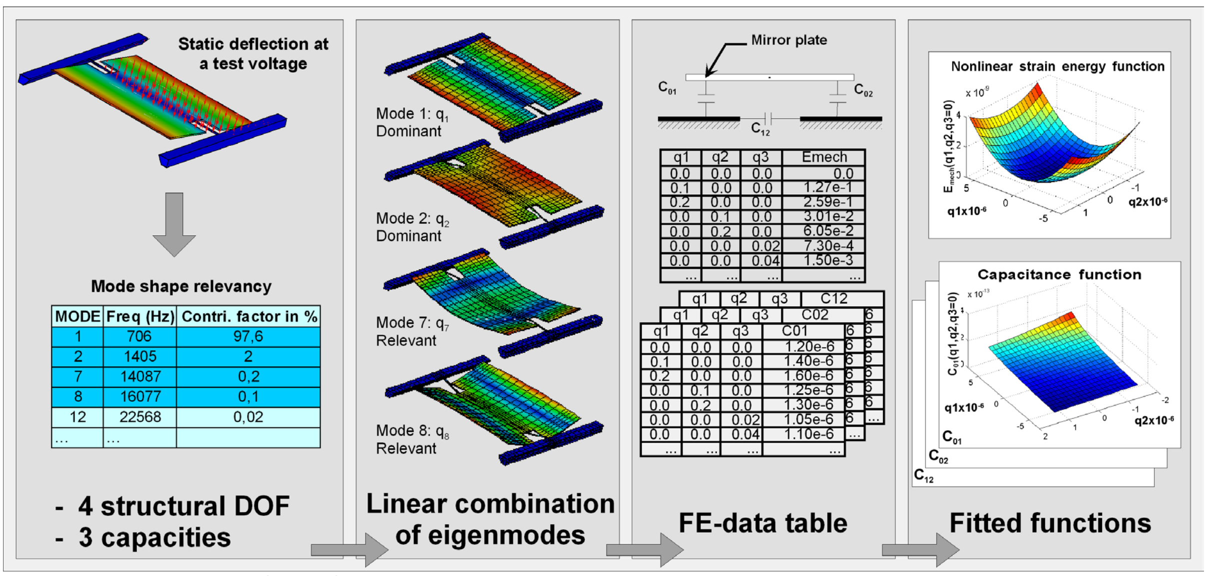


**Fig. 1:** Generation pass flow of a 1D micromirror

the kinetic and the potential energy (elastostatic and electrostatic) for a proper and sufficient system description. These functions will be fitted from data points that are computed by a series of FEM simulations.

Following the top down design strategy, one can split the **R**educed **O**rder **M**odelling (ROM) procedure in three phases. The first phase is called macromodel *generation pass* (Fig. 1) and includes all necessary steps from finite element parameter extraction, energy function fit up to establishing the final component description. This process is computationally expensive but has to be done just once producing a black-box model with functional access only at its interface pins. The second phase is called macromodel *use pass*. The black-box model is placed in the same or another design environment and enables very fast simulations. The third phase is called *expansion pass*, where the deformation state, stress distribution or electrostatic field quantities of the entire microstructure can be visualised at chosen time steps.

A virtual laser writer on a 2D-Projection area is used to demonstrate the macromodel in action on system level simulation (Fig. 2). Thereby two micromirrors are used for laser deflection (The first one for horizontal- and the second one for vertical laser deflection). Both micromirrors are excited by nonharmonic deflection functions. Hence, feedback controller circuits are necessary to guarantee stable operating conditions with minimal overlaying oscillations. The diagrams (a), (b) and (c) of Fig. 2 show the simulation results of the micromirror for horizontal deflection. It could clearly be shown that reduced-order models for the controlled system (micromirror) are more precise than network representations to tie continuous systems (MEMS) and discrete electronic circuitry together. Fig. 2 (d) shows the simulated projection of a figure (ROM TOOL). The MEMS component is modelled in ANSYS with about 7000 solid elements. Energy data are extracted for four modes and three electrodes in about 5 hours, while the function fit itself takes just a few seconds. Despite the computational effort in the generation pass, advantages become obvious at the use pass. Transient simulations can be done in almost the same time as single degree of freedom models would need. Not only the tilt angle but also transverse motion and plate warping agrees well to fully coupled 3D finite element simulations.

Presently, the macromodel generator that performs the generation pass is implemented in MATLAB as "ROM-TOOL". It requires access to ANSYS/Multi-physics and to a detailed user-defined FE-model of the micromechanical structure. Interfaces to convert the reduced order macromodels into VHDL-AMS, PSPICE and SIMULINK syntaxes were established and make the ROM-generator compatible with most commercial EDA tools.

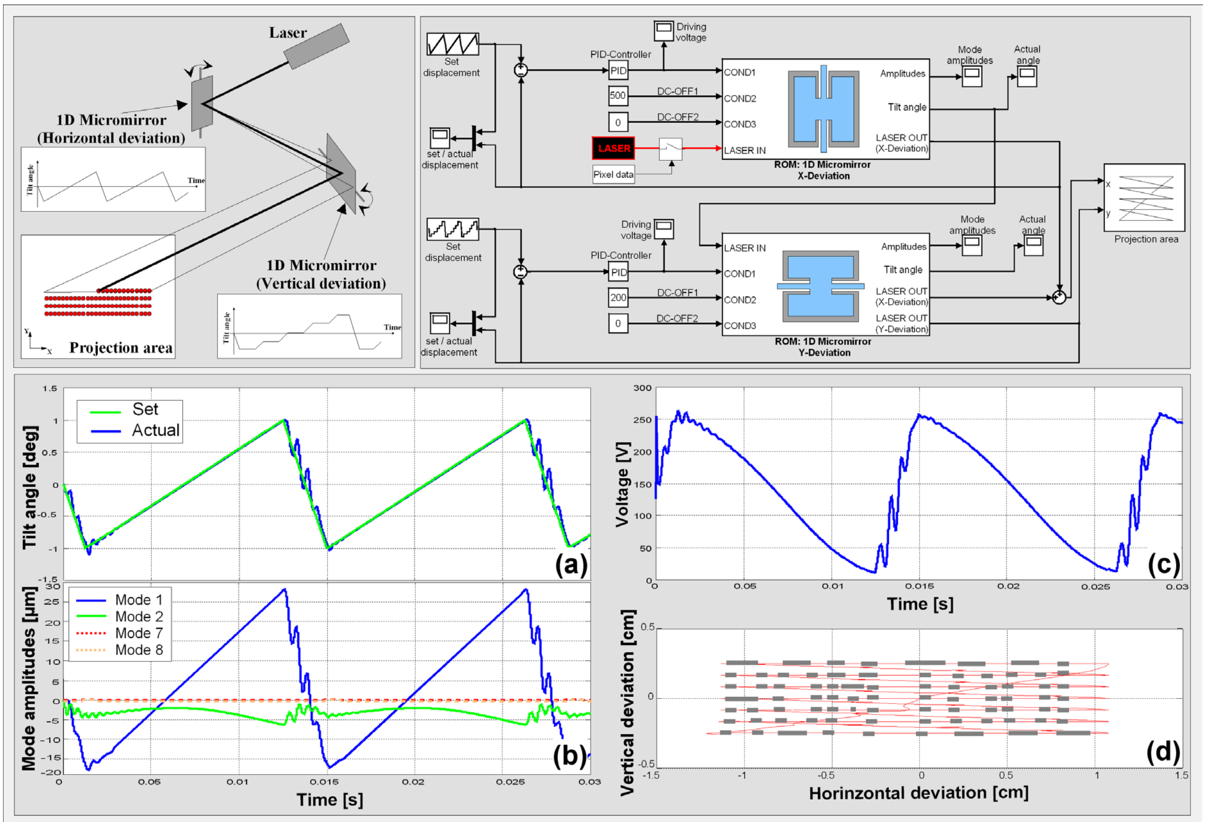


**Fig. 2:** Example of a system simulation of the generated macromodel (2D laser projection)