Application Note: SMASH-Simulation of a Surface Micromachined Deformable Mirror Device

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1 The Deformable Mirror Device

We show the suitability of our approach by simulating the deflection of a deformable mirror device (DMD) together with its controlling circuit. The DMDs are deflectable mirrors which are arranged in a matrix on the chip, see [5,6] for details. Depending on the voltage at its electrode, each DMD can be deflected separately. In this way, the resulting phase or amplitude modulation of incoming light can be used to create a pixel image on a screen. Various schemes have been proposed for DMDs. Here, a simple, quadratic, reflecting plate is used. This plate is fixed on two sides, see figure 1.

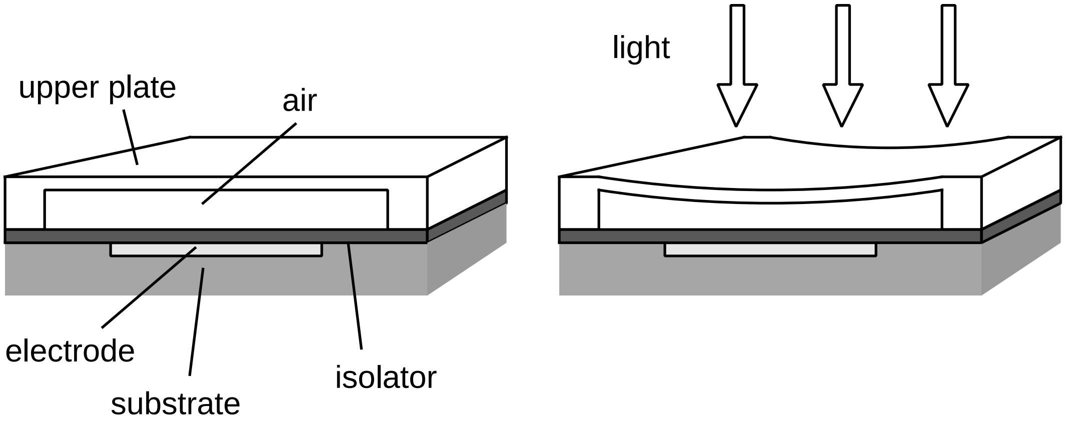

Figure 1: Simple configuration of a deformable mirror device.

For the upper plate, the following partial differential equation is solved to calculate the deflection.

$$\frac{\partial^2 u}{\partial t^2} = \frac{EI}{\rho A} \cdot \frac{\partial^4 u}{\partial x^4} + \frac{w(x,t,u,\dot{u})}{\rho A}.$$

E is the modulus of elasticity, I the moment of inertia, ρ the density of the plate material, A the cross-section of the upper plate and w the excitation, i.e. the electrostatic force caused by the voltage between electrode and upper plate.

The controlling circuit is used to address the DMDs and to set the electrode's voltage. It is similar to a controlling circuit of a DRAM. Figure 2 shows the complete configuration of one DMD with select and data line.

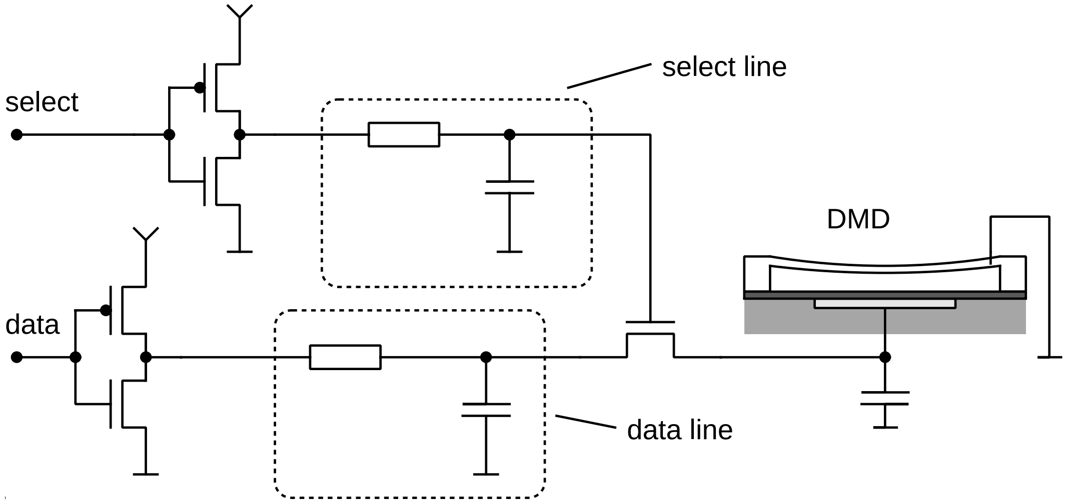

Figure 2: DMD system.

2 Generating ABCD models

We apply the finite differences method (FDM) to transform partial differential equations to sets of ordinary differential equations which can be directly formulated in Dolphin's analog hardware description language ABCD. The spatial variables of the partial differential equations are discretized and an algebraic equation is inserted for each node. This equation describes the behavior of the respective slot by regarding itself and some of its neighbors in both directions. The transformation of spatial derivatives up to the forth order can be done. For example, the equations containing the term $\frac{\partial^4 u}{\partial x^4}$ have to be duplicated n times, if n is the number of steps of the discretization. Each of these duplicated equations represents another node of the discretized domain, see Figure 3. For the spatial derivative of the above form, two neighboring nodes to the left and right have to be taken into account. This implies two additional nodes on the left and right side of the discretized domain. These nodes contain the boundary constraints.

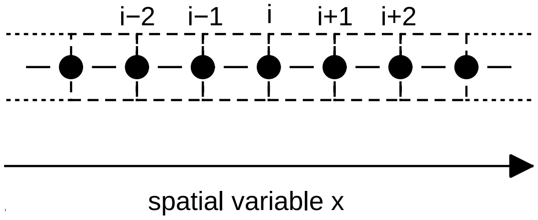

Figure 3: Discretization of spatial variable x.

Currently, arbitrary partial differential equations in one dimension and up to the forth order spatial derivative can be translated to ABCD by the transformation tool meXel.

Coefficients, e.g. the modulus of elasticity or thermal conductivity, may be dependent of time and space. The equations for the following phenomena can be formulated: bending of elastic plates and beams, heat- and material-transport, diffusion and lossless wave propagation.

3 Simulation

The goal of this work is to cosimulate the electronical and mechanical parts of the system simultaneously with one simulator, i.e. Dolphin's SMASH, and one simulation approach. The following aspects of the DMD system behaviour can be examined:

- shape of the bending line
- eigenfrequency of the upper plate
- change of electrostatic forces depending on the bending line
- damping effects
- influence of the changing capacitance on the electronic circuit

Especially, the interaction between electronics and mechanics can be studied: the deflection of the upper plate initiates a positive feedback effect, since it reduces the air gap. This increases the electrostatic field between the plates and the force which caused the deflection becomes even stronger. This effect is shown in the first simulation example which is a quasi-static simulation in which the excitation voltage is linearly increased to 25V.

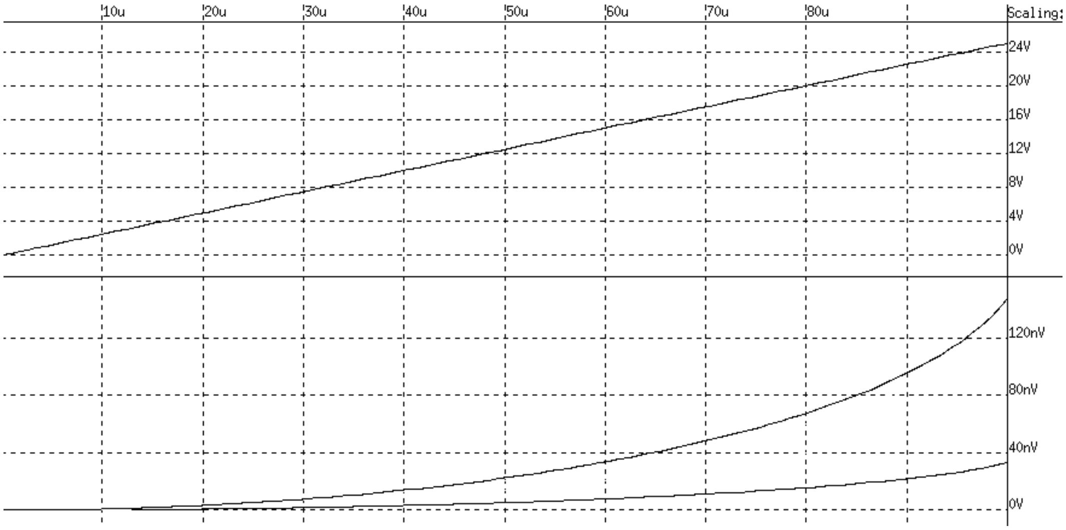

Figure 4: Quasi-static simulation of deformable mirror device: excitation voltage (top), displacement of several points on the bending line (bottom, 1nV = 1nm).

The second simulation example deals with a transient simulation of the DMD and its controlling circuit. Figure 5 depicts the excitation voltage and the plate displacement at several nodes. The amplitude of the deflection depends on the location of the current node, but the frequency, i.e. the eigenfrequency, is constant. The absolute value of the displacement is about 15 % lower than in the statical simulation with 25 volts excitation. This is due to the voltage drop caused by the controlling circuit. The actual excitation voltage at the DMD device is about 23.6 volts though 25 volts was chosen for input and supply voltages. The simulation takes about 45 CPU-seconds on a SUN Sparc 20^{TM}.

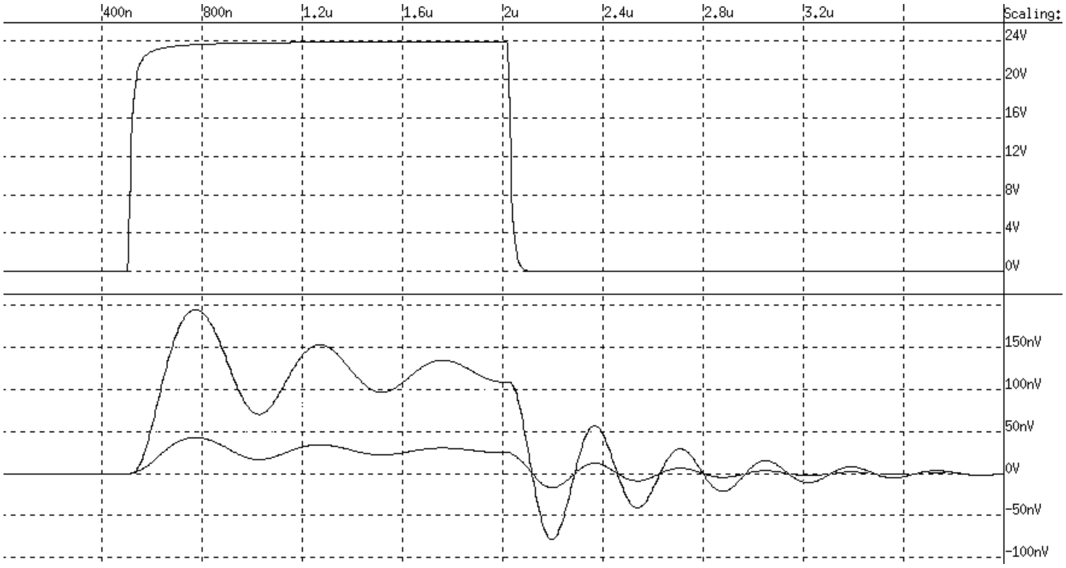

Figure 5: Simulation of deformable mirror device: excitation voltage (top), displacement of several points on the bending line (bottom).

4 References

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