

Position Encoding and Phase Control of Resonant 2D-MOEMS Mirrors

Tortschanoff, Andreas¹, A. Frank¹, M. Wildenhain², T. Sandner², A. Kenda¹

¹Carinthian Tech Research AG, Europastrasse 4/1, A-9524 Villach, Austria

²Fraunhofer Institute for Photonic Microsystems, Dresden, Germany

Introduction

Resonantly driven oscillating MOEMS mirrors are of high interest for various fields in optics, telecommunications and spectroscopy. Resonant driving of scanning mirrors has several advantages, including high mirror deflection angles, which can be obtained at relatively low driving voltages and with minimal energy consumption. For stable oscillation with large amplitude, operation close to resonance must be ensured under varying environmental conditions.

Due to their small weight MEMS mirrors are shock and vibration resistant and can feature high scanning rates (up to 30 kHz). Finally the small device dimensions and possible low production costs are important features with regard to mass production. On the other hand, resonant scanner mirrors can only be driven with a sinusoidal trajectory, thus the projection patterns for the 2D scanners are limited to Lissajous-type figures. Furthermore there is no inherent position feedback of the movement of the mirror.

To facilitate system integration of these MEMS mirrors, we have developed a compact device comprising optical position sensing, and driver electronics, with closed loop control, capable of driving resonant 1D-MOEMS micro-mirrors [1]. The approach is very flexible and especially applicable for high frequency devices, where synchronized excitation [2] is difficult.

Very recently, we extended our approach to 2D scanner mirrors, which significantly increases the complexity of the device. In the following we present the position encoding and feedback scheme of the novel 2D unit.

Scheme

Micromechanical scanner mirrors, as the ones shown in the inset of Figure 1, are fabricated using CMOS compatible technology [3]. The 1D-mirrors consist of a plate suspended by two torsional springs and two comb like driving electrodes. In the 2-D mirrors the inner frame is further suspended by orthogonal springs and driven by another pair of electrodes. The mirrors are driven electrostatically with a pulsed driving voltage close to the double of their eigenfrequency.

The amplitude is frequency dependent and the resonance frequency, where the amplitude is maximal, depends on environmental parameters like temperature (c.f. Figure 1), driving voltage, or pressure.

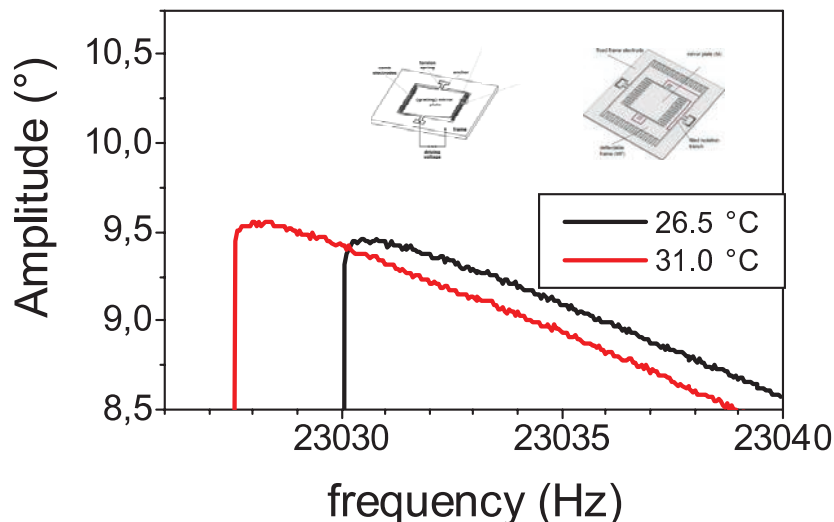


Fig. 1. Amplitude as a function of frequency close to resonance for a MOEMS mirror at two different temperatures. Insets show the design of a 1D and a 2D MOEMS device.

Position encoding of the mirror movement is crucial for most applications. This can be done by measuring a laser beam reflected from the backside of the mirror.

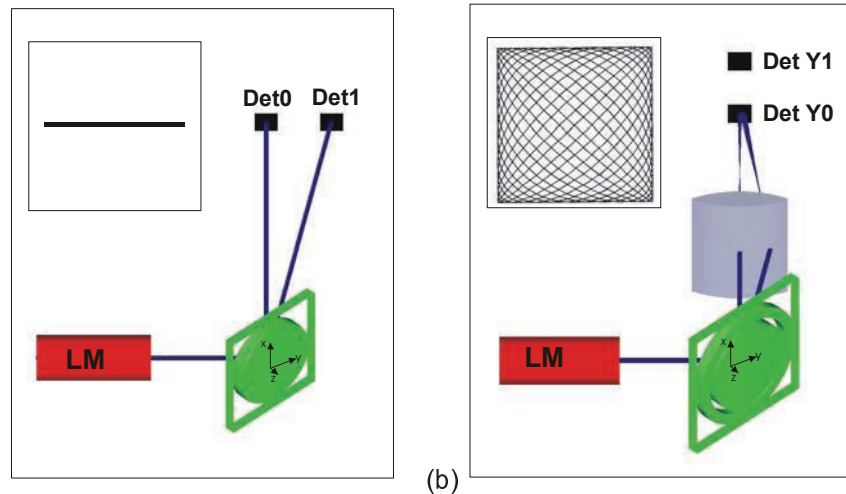


Fig. 2. (a) Scheme of the optical position sensing principle for the 1D-device. Inset shows the line projected by a 1D device. (b) Scheme of the position sensing for the 2D device. Inset shows a typical Lissajous pattern, which is projected by a 2D device.

As depicted in Fig. 2, the beam from a red laser diode module (LM) is reflected at the backside of the MOEMS mirror and hits two fast photodetectors Det0 and Det1, which measure the timing of the passage at the zero position and at a fixed angular deflection, respectively. This scheme is straightforward for a 1D scanner and completely determines the angular movement [4]. Our device assumes purely sinusoidal motion of the mirrors but the approach could easily be extended to other periodic trajectories. In principle, only one diode at a well defined position would be sufficient to determine the motion of the mirror. But the additional detector at zero deflection significantly increases the precision of the measurement, in particular with regard to the delay between zero-transition of the mirror and the driving signal. And, as discussed below, it is exactly this phase delay, which is measured and minimized in closed loop operation in order to work at the resonance frequency.

A 2D-Scanner mirror oscillates around two orthogonal axes with different frequencies. A reflected laser beam then describes a Lissajous pattern, as shown in Fig. 3(b).

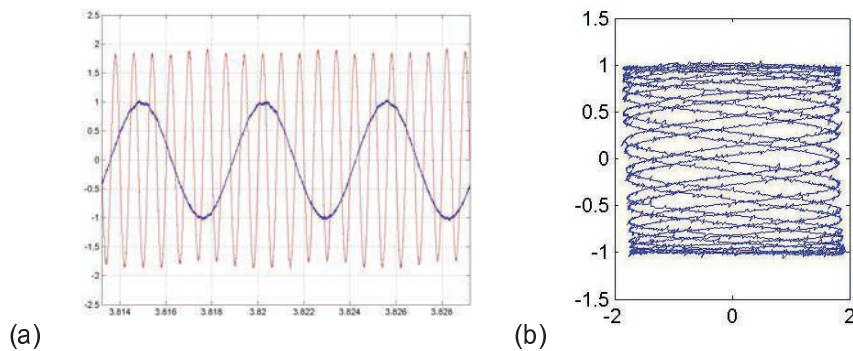


Fig. 3: X- and Y- signal from the PSD: (a) individual traces, (b) plot y vs x (see text for details)

In this case, position feedback, using the scheme outlined above, is not straight forward, since it must be ensured that the photodiodes are hit for each axis during each cycle. This can be realized using cylindrical optics, which compensate for the deflection along one of the axes. This is schematically shown in Fig. 2(b). There angular deflection around the x axis is compensated by a cylindrical lens and the angular deflection around the y axis is measured similar to the 1D case. For the other axis a second orthogonal laserbeam can be used. This reduces the problem to the control of two independent 1D-oscillations and allows accurate position sensing and closed loop control.

In our device we use cylindrical mirrors instead of lenses in order to obtain a compact design. This is schematically depicted in Fig. 4.

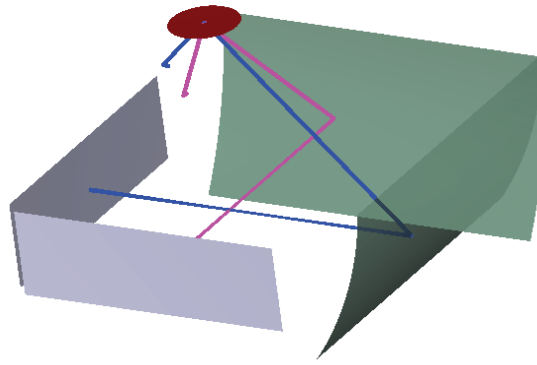


Fig. 4: Basic scheme of the optical layout in the 2D device, which consists of the MEMS mirror (red) and two crossed cylindrical mirrors (large grey surfaces), which steer the beams to the corresponding detectors (blue rectangles) (Some beam-steering mirrors are not shown).

The control scheme of amplitude and phase in the 1D-mirror device was described in much detail previously [5]. In short we determine the phasedelay pd , defined as the delay between the falling edge of the driving voltage and the zero-crossing of the mirror. By adjusting the frequency f in order to minimize this delay, operation at resonance can be obtained. The phase φ , expressed in degrees, is given by $\varphi = \frac{pd}{T} 360^\circ$, where $T = \frac{1}{f}$ is the period of the mirror oscillation. Furthermore, by measuring the delay between two successive zero crossings, small misalignments of positioning of the trigger diode, can be corrected [5]. The amplitude can most conveniently be determined by measuring the delay t_A between two successive trigger pulses from the amplitude diode and using $A = \frac{X_0}{\sin(\pi(\frac{1}{2} - \frac{t_A}{T}))}$, where X_0 is the known position of the amplitude diode.

Fig. 5 provides an overview of the interdependencies in our control concept. In fully controlled mode, we continuously adjust the frequency for minimal phasedelay, which assures operation at resonance, and then adjust the driving voltage to keep the amplitude constant. Since the phase dependence on driving voltage is rather small, this scheme converges quickly and provides stable operation.

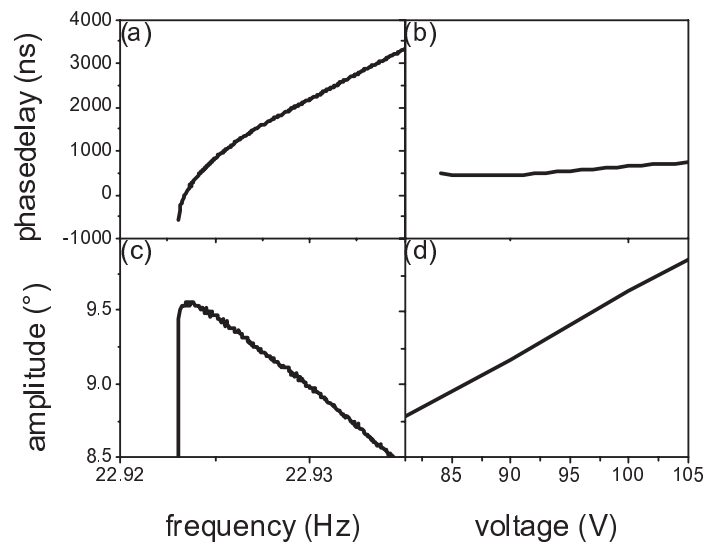


Fig. 5: (a) Phasedelay as a function of frequency for a fixed driving voltage of 100 V. (b) Phasedelay as a function of driving voltage for a fixed driving frequency of 45.85 kHz. (c) Amplitude as a function of frequency. (d) Amplitude as a function of driving voltage. (taken from [4]).

Results

This control approach was successfully implemented for the case of 1D scanner mirrors [1]. In our device, shown in Fig. 6(a), which has a size of only $\sim 1 \text{ cm}^3$, the timing is measured and controlled with a precision of $<10 \text{ ns}$ (corresponding to a phase difference of 0.01°).

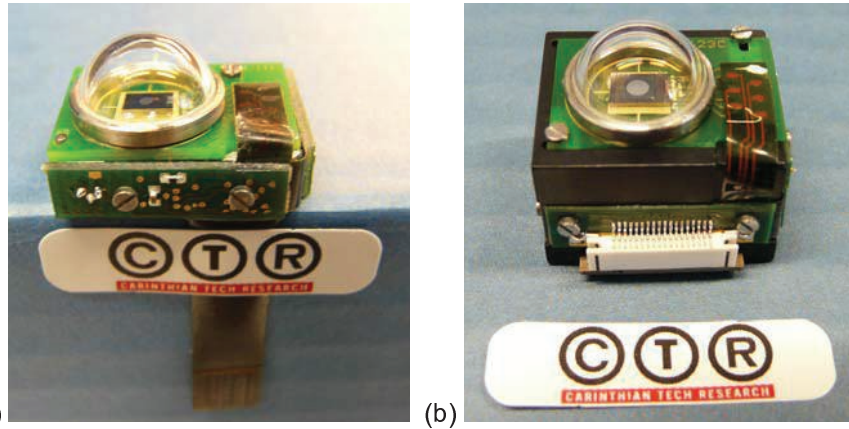


Fig. 6. Photos of the (a) 1D-device and (b) 2D device.

In addition, for the projection of a stable Lissajous pattern, also the phase between the oscillations of the two orthogonal axes must be controlled. In our approach the fast axis is phase stabilized in order to be driven close to resonance. To ensure a stable Lissajous pattern the slow axis must be readjusted in such a way, that the frequency ratio of the two axes stays constant. For this, we implemented a closed loop control, where the timings of the zero transitions of the y- and x- axis are compared once per frame. Any deviation from zero (or from a given target time) is compensated by slightly adjusting the frequency of the y axis.

Preliminary experiments indicate the abilities of this device and are shown in Fig. 7.

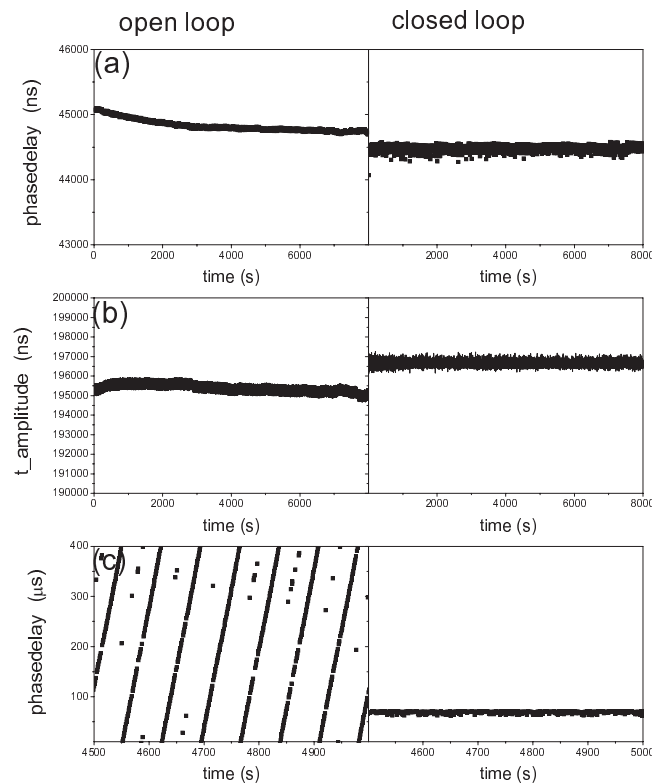


Fig. 7: (a) Phasedelay, (b) amplitude of the fast axis and (c) the relative phase in the 2D-device under normal working conditions.

Conclusions

Closed-loop control of MOEMS mirrors will significantly improve the performance of these devices. Extending this possibility to 2D scanners will be highly relevant e.g. for the development of compact projection devices. The first experimental results prove the feasibility of our phase-locking concept and demonstrate the abilities of our device. In depth characterization of the 2D device is currently ongoing.

Acknowledgements

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References

- [1] A. Tortschanoff, M. Lenzhofer, A. Frank, M. Wildenhain, T. Sandner, H. Schenk, A. Kenda, *Procedia Chemistry* 1, 1315 (2009)
- [2] K. Roscher, U. Fakesch, H. Schenk, H. Lakner, D. Schlebusch, *Proc. SPIE* 4985, 121 (2003)
- [3] H. Schenk, P. Dürr, D. Kunze, H. Kück, *International Mechanical Engineering Congress and Exposition, MEMS-Vol. 1*, pp. 333-338, Nashville (1999)
- [4] A. Kenda, W. Scherf, R. Hauser, H. Gröger, H. Schenk, *Proc. IEEE Sensors* 2004, 1312 (2004)
- [5] Tortschanoff, A., Lenzhofer, M., Frank, A., Wildenhain, M., Sandner, T., Schenk, Scherf, W., Kenda, A., *Sensors and Actuators A* 162, 235–240 (2010).