ANALOG DRIVER FOR SYNCHRONIZED QUASI-STATIC MOEMS MIRRORS

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Abstract — **In this paper we present for the first time an analog control loop for positioning micro optical mechanical system (MOEMS) mirrors. The measured results are compared to the characteristics of the devices when driven in open loop mode. MEMS mirrors achieve more and more interest in miniaturized applications for example spectrometers and scanner devices. To obtain better physical properties, especially an increased aperture in scanning devices, several devices have to be synchronized to each other. This represents a major challenge because the MOEMS elements show a spread in their mechanical properties like resonance frequency and response curve. When using this control loop circuit presented in this paper, synchronization for each mirror can be achieved very easily, because the parameters are adjusted individually for each device. Consequently the same set-point signal leads to the same mirror deflections. In this contribution we present the principle of the quasi-static driver concept and show the experimental results achieved with a 470 Hz quasi-static mirror, which demonstrates its capabilities but also show its limitations.**

Keywords : **MOEMS mirror, MEMS device, quasi-static mirror, analog control loop, position control, MEMS driver**

I - Introduction

A number of MOEMS based projection displays[1], imaging devices, barcode readers[2], spectrometers[3] and infrared imaging cameras have been developed for industrial, medical and consumer market. Especially for scanner products one fast oscillating mirror axis or even two axes to project a 2D raster pattern are necessary. To achieve a larger aperture an array of synchronized micromechanical devices can be used. Quasi-static mirrors can follow arbitrary trajectories and as such have several advantages.

The advantage of driving MEMS mirrors is that high mirror deflection angles can be achieved at relatively low driving voltages and minimal energy consumption. Additionally they are shock and vibration resistant and feature high scanning rates caused by the low mass of the mirror element.

To guarantee proper functionality, meaning stable well-defined amplitudes even under varying environmental conditions, it is essential to implement a closed loop control[4]. Our driver position feedback is obtained by integrating a PSD device to detect the position of the mirror element. The advantage of performing one controller stage for each mirror element is that they can be supplied with the same input signal and thus are automatically synchronized because they lock onto the same reference signal.

In this contribution we present our driver circuit for a quasi-statically driven mirror device including the feedback scheme, and show first experimental results with a quasi-static mirror. While our circuit is specially designed and adjusted to control a specific device, the basic concept is viable for all kind of quasi-static micro actuators.

II - MOEMS Device and driving Principle

The quasi-static micromechanical mirrors used for our development are commercially available devices from Mirrorcle Technologies Inc.®[5]. Figure 1 shows a photograph of the device we used. The MEMS actuator is fabricated in monolithic single crystal silicon and consists of 2-dimensional, gimbal-less vertical comb driven structures[6]. The mirror plate is fabricated in a separate SOI process and metalized before it is bonded to the actuator. The MOEMS mirror achieves a maximal amplitude of approximately 6.56° at 123 V. The resonant frequency depends on the used axis and is between 466 Hz and 470 Hz.

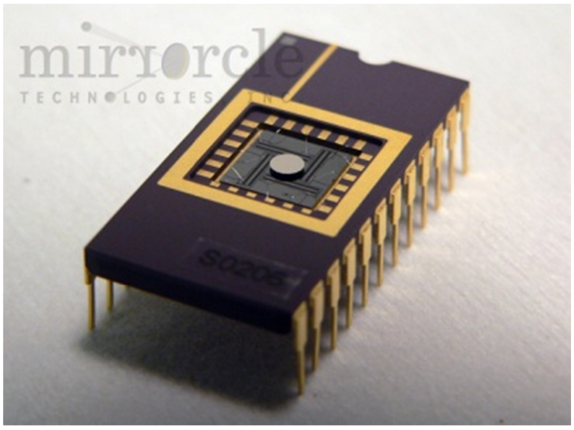


Figure 1: *Photograph[5] of the quasi-static mirror used to test our driving concept.*

To drive this MOEMS device a differential high voltage scheme with an additional bias voltage is used, which can be adjusted to prevent damage of the device. The advantage of this method is that it linearizes the device characteristic and provides smooth transitions when moving from one quadrant to the other. Figure 2 shows the basic diagram of this driving method and the characteristic curve of the device.

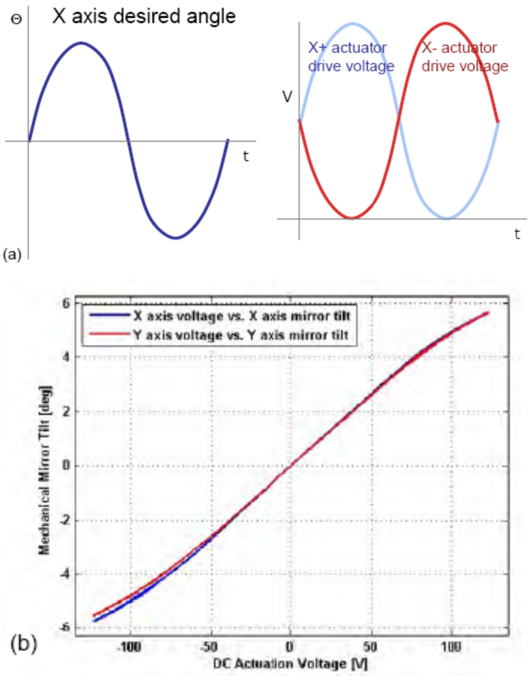


Figure 2: *a) Deflection angle of the mirror plate with the linearized 4-quadrant driving scheme. b) Mirror deflection angle dependent on the applied driving voltage*[5].

III - System Integration and Results

Figure 3 shows the developed driver box that contains two independent high voltage drivers in order to synchronize two quasi-static mirror devices. For the feedback path two dimensional PSD circuits are used, which generate an output voltage of ±3 V depending on the power of the reference laser diode. Because of the fact that the implemented high voltage driver board accepts levels of approximately ±9 V to achieve the maximal output voltage of up to +140 V, an additional power supply was inserted that supplys the output amplifiers. The set-point signal for the PID controller is applied to the Sub-D plug. All other signals are just supply wires and indicator lines from the PSD device to achieve the possibility to monitor or adjust the optical configuration.

Figure 3: *Photograph of the developed high voltage driver box to drive two synchronized quasi-static mirrors.*

To control the quasi-static axis, an analog PID controller was designed. Figure 4 shows the realized circuit. It consists of a first order input filter followed by an input amplifer, which can be configured very flexibly, either to use it as inverting or non inverting amlifier or impedance amplifier. This flexibility was necessary to achieve the possibility to use different laser modules, which lead to higher or lower signals on the PSD. The next stage is an adder circuit that substracts the actual value from the desired set point value. Afterwards the difference is weighted by three independent stages representing the integral, the diffrential and the proportional value of the PID controller. The feature to adjust all the values independently is very important, because every MOEMS miror has sligtly different parameters. The transfer function of the implemented controller is given by:

$$F(j\omega) = K_R\left[1 + \frac{1}{j\omega \cdot T_N} + \frac{j\omega \cdot T_V}{1 + j\omega \cdot T_1}\right]$$

with

$$K_R = \frac{R_{11}}{R_{4,14,20}}, \quad T_N = R_3 \cdot C_1, \quad T_V = R_{17} \cdot C_5$$

and

$$T_1 = R_{19} \cdot C_5 .$$

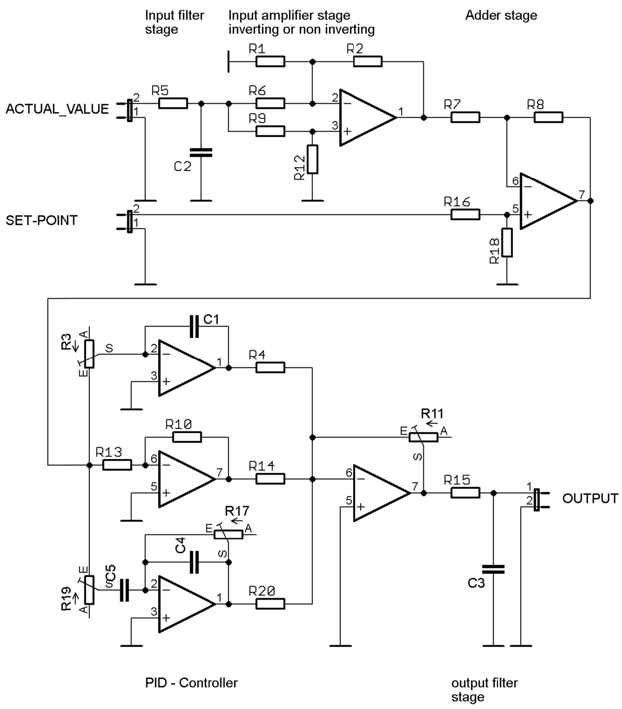
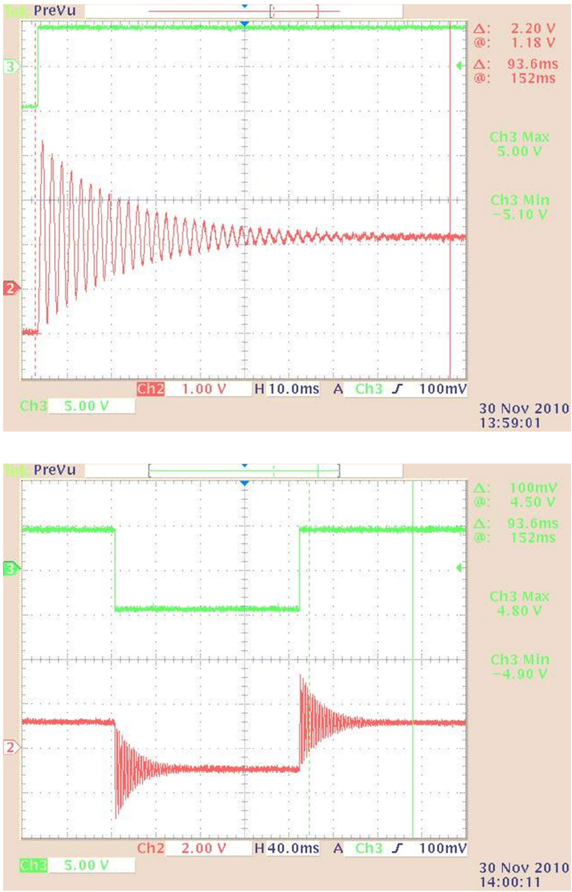


Figure 4: *Schematic of the realized PID control loop.*

Before starting the adjustment of the PID controller the step response signal of the quasi-static mirror was measured. Figure 5 shows the measured signals.

a)



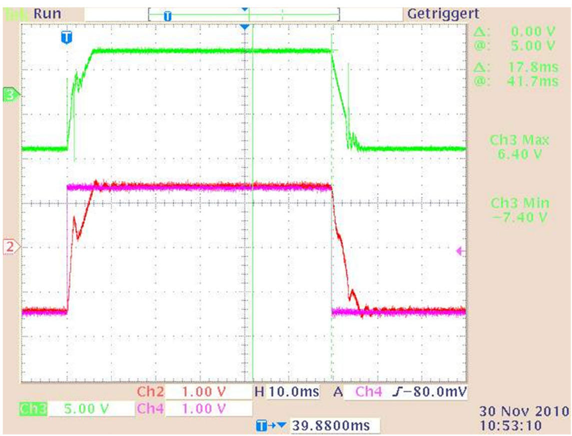
b)

Figure 5: *a) Detailed zoom of the step response signal. The mirror oscillates with its eigenfrequency of about 80 ms before reaching a quasi-stationary position. b) The mirror response is identical on both, raising and falling slope of the control signal.*

In the next step the PID controller parameters were adjusted, so that the following optimized signal curves could be measured, figure 6.

For a scanner application, where the movement of the mirror could define the vertical deflection, a constant linear variation would be of interest. Therefore the input signal form was changed from a rectangular waveform to a triangular one. Figure 7 illustrates the measurement results with this trajectory.

a)



b)

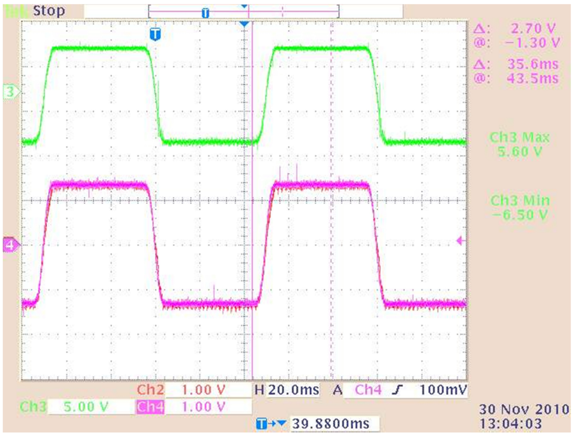
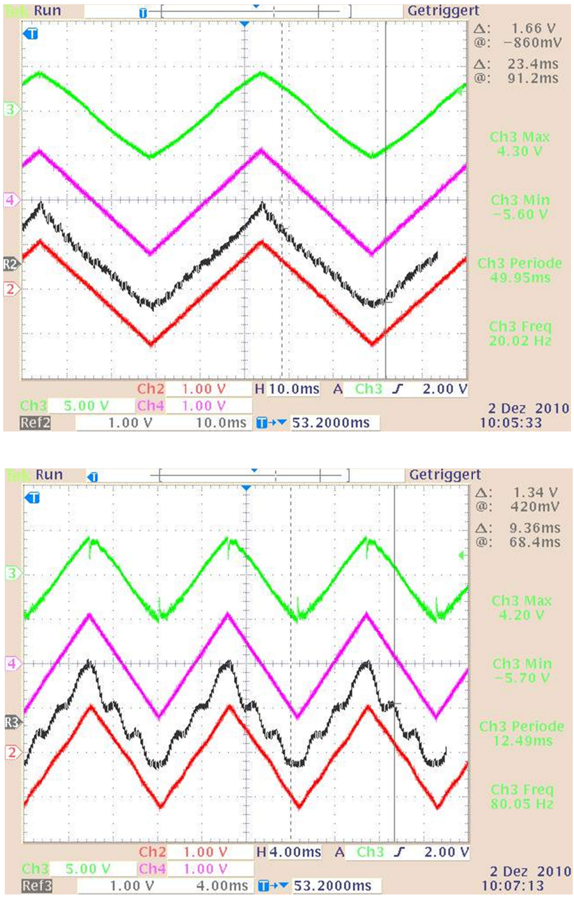


Figure 6: *a) This diagram shows the achieved step response of the mirror when implementing it into the PID control loop. The speed of reaching the maximum deflection could be increased so that the mirror now just requires 8 ms anymore to reach a quasi-stationary position. b) Measurement when driving the mirror in open loop, where the rectangular control signal is filtered by a Bessel low-pass with a bandwidth of about 180 Hz.*

a)



b)

Figure 7: *a) Signal 4 is the input signal, which sets the position of the mirror. Signal 3 represents the output of the PID circuit that controls the HV stage. Signal 2 indicates the mirror movement measured by the PSD. R2 is the signal of the PSD when driving the mirror in open loop. The measurement was done at a frequency of 20 Hz. b) The signals are still the same, but the measurements were done with a frequency of 80 Hz.*

At higher frequencies it can be seen, that the resonance frequency of the mirror leaks into the measured position signal, if driving the mirror element in open loop. The reason is that every abrupt change in the control signal leads to an excitation of the eigenfrequency of the mirror. The effect is stronger if the frequency gets closer to its eigenfrequency. This means that it is very important to use a controlled driver design to achieve higher scanning frequencies and also much more precision.

CONCLUSIONS

In this article we presented a novel unit for closed-loop control of electrostatically driven quasi-static MOEMS mirrors, which will significantly improve the performance of these components.

The experimental results prove the possibility to drive quasi-static mirror elements within a PID control loop. The control circuit leads to a 10 times faster position reaching than just driving the mirror in an open loop circuit and even much more precision. When using a PID controller it is also possible to achieve higher control frequencies. As long as the set-point signal's frequency is 6 times lower than the mirror's eigenfrequency the given trajectory is followed perfectly.

This control concept is perfectly convenient to synchronize more mirror elements, because after connecting them in parallel, every mirror controller locks onto the same input frequency or analog signal. We expect it to provide significant impact for applications of these MOEMS mirrors e.g. in compact projection devices.

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