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High Voltage Driver Design for Actuating a MOEMS Mirror Array

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Abstract**—**In this paper we present a new multichannel high voltage driver box to connect up to six MOEMS mirror devices to it that have resonant and also quasistatically driven actuating electrodes. It is possible to drive all resonant axes synchronously while the amplitude of them can individually be controlled by separate microcontrollers that also operate the quasistatic axes. Circuit simulations are compared with the measurements done on the real system and also show the robust driving performance of a MOEMS mirror.

Keywords**—** MOEMS, scanner mirror, electrostatic driver.

I. Introduction

MOEMS scanner mirrors are of importance in various fields in optics, telecommunications and spectroscopy. They gain more and more importance to satisfy the industry demands for light-weight, miniaturizable, and cheap solutions for many opto-mechanical applications. Among others, micromechanical resonantly driven scanning mirrors are used in bar-code scanners [1], miniaturized spectrometers [2], light barriers [3], and other applications. 2D-scanning mirrors are at the core of different projection applications [4] – [6].

With resonantly driven mirrors only sinusoidal trajectory can be achieved, thus the projection patterns for 2D scanners are limited to Lissajous-type figures. Arbitrary trajectories can be obtained with quasistatic MOEMS mirrors [7]. Such micro-mechanical scanner mirrors are fabricated at the Fraunhofer IPMS using CMOS compatible technology [8], and consist of a plate suspended by torsional springs and comb like driving electrodes. The vertical sides of the electrodes and the mirror plate form variable capacitors, which are decreasing with increasing deflection angle of the plate. A high voltage generates an electrostatic torque, which accelerates the plate towards its rest position of the oscillation [9].

When driving a resonant mirror with a fixed driving frequency the mirror will oscillate with half this frequency. In general, there will be an offset in the timing of the zero-deflection point with regard to the switching off of the driving voltage, depending on the deviation of the driving frequency from exact resonance. Furthermore there is an ambiguity concerning the direction of the mirror motion inherent in this electrostatic driving principle.

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While for quasistatic MOEMS mirrors, exact calibration of the driving characteristics might be sufficient, for electrostatically driven resonant scanner mirrors, position feedback must be provided for any application, which requires information about the actual mirror motion.

Therefore driver electronics is necessary that either supports multiple driver circuits to supply several axes, ADCs and microcontrollers to read in the position signals and also an FPGA circuit that supports synchronization for all MOEMS mirror devices.

II. Overview Of The Driver Electronics

The MOEMS mirror driver board was designed to be able to control and synchronize up to six devices each consisting of one resonant axis and a quasistatic mirror axis. Dependent on the fabrication process of the MOEMS device one high voltage driver stage is needed for the resonant axis and additional two to drive the quasistatic axis. This leads to a total count of 18 high voltage driver stages. To simplify the design process a modular approach was used, meaning that the controller circuit was designed on separate PCBs for each mirror while the high voltage DC/DC converter and the amplifier stage was assembled on the main board. The reason for the central amplifier stage on the main board is that an integrated device was used, with the capability of 32 axes. Additionally an FPGA module was assembled on the main board that has the task to either distribute all the signals from the control computer to the single axis microcontrollers and also to ensure phase synchronization between all six resonant axes. Therefore the position signal of each axis, which is digitized on the small microcontroller PCBs are compared to the reference clock signal applied to the input connector. The FGPA delays the control signals for the high voltage amplifier to achieve best synchronization to this reference clock.

The microcontroller boards contain the amplifier stages for the feedback signals of the resonant and quasistatic axes, a zero-crossing comparator that converts the sinusoidal position signal of the resonant axis back to a digital one that is fed back to the FPGA on the main board for the synchronization logic, a peak level rectifier that extracts the maximal amplitude corresponding to the mechanical deflection of the mirror device and the microcontroller with an attached DAC circuit. The microcontroller performs two main tasks – first of all it enables the position control algorithm for the quasistatic axis and on the other hand it also controls the amplitude of the resonant axis. The amplitude values for the resonant axes are changed only very few times and compensate the slow drift occurring if temperature changes or the supply voltage varies. The set value for the amplitude is received from an external PC and the microcontroller compares it with the rectified peak level of the position feedback. If a difference occurs the controller increases or decreases the value before writing it to the DAC. Figure 1 illustrates the block diagram of the final driver electronic circuit which can drive up to six MOEMS devices.

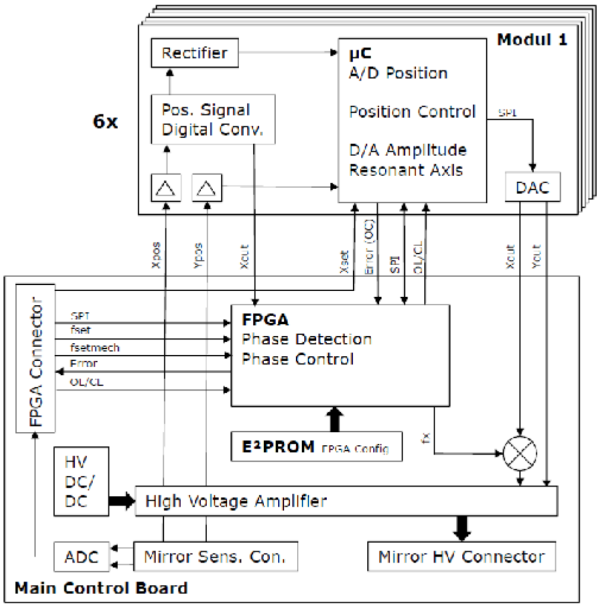

Fig. 1 Block diagram of the control unit

Figure 2 shows a photograph of the whole driver electronics. The whole electronics was designed on a PCB with a size of 160x100mm and consists of six layers.

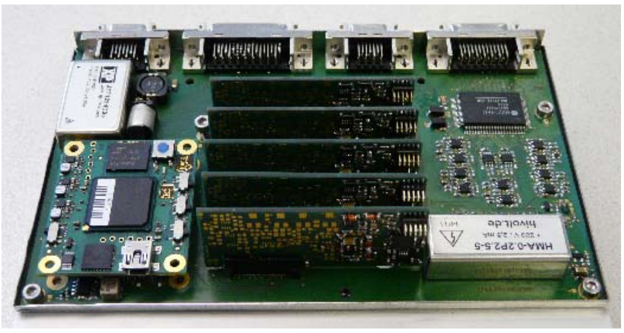
Fig. 2 Picture of the final driver board

III. Mainboard Electronics

The electronic components on the mainboard are arranged in four groups: the linear high voltage amplifier stage that supplies all the resonant and quasistatic axes of the mirror with up to 200 V, the FPGA module that synchronizes all resonant axes and performs the peripheral control logic block, the ADC block to simultaneously measure the position of one receiving and the transmitting mirror and the voltage regulator block to generate all necessary voltage levels from the 12V power supply.

While for the FPGA a commercial module and for the power supplies DC/DC converters where used the main development focus lay on the control circuits of the high voltage stages. In general it has to be distinguished between the resonant and the quasistatic drivers.

For the resonant axis a rectangular control signal with a varying amplitude value send by a command from a PC is applied to the amplifier stage. The frequency is adjusted to twice the mechanical resonance frequency of the mirror device. To generate this signal a modulator is necessary that is build up with a monolithic CMOS SPST switch [10] figure 3, which provides low power dissipation at high switching speed, low on resistance and low leakage currents.

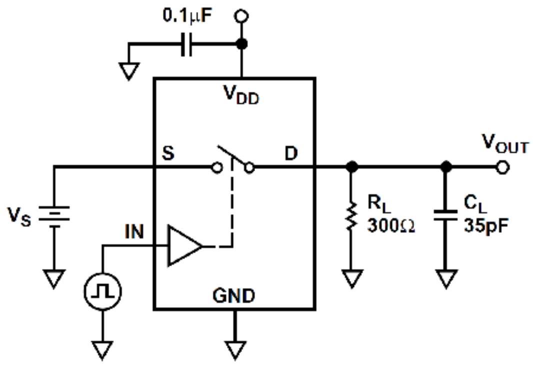

Fig. 3 SPST switch configuration where VS represents the voltage amplitude of the DAC and the LVTTL rectangular signal from the FPGA is wired to the IN pin of the device leading to an output signal Vout that represents the modulation product of both signals

For one quasistatic axis two drivers are necessary dependent on the fabrication process. The mirror plate forms with the frame electrodes a differential capacitor, refer to figure 4. If a potential is applied to one electrode the mirror plate deflects to one side while it changes its direction if the potential is applied to the other one. In each case the mirror plate is referenced to ground.

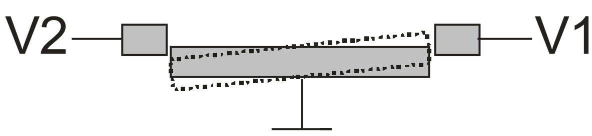

Fig. 4 Picture of the quasistatic MOEMS mirror design

If a single control trajectory of a DAC in a range of 0 V to 4.096 V is applied, it is necessary to adjust it to appropriate control signals for the two electrodes. The 4.096 V is defined because the high voltage amplifier gains the input signal by the factor of 50 resulting in a final high voltage value of approximately 200 V. The circuit simulation in figure 5 shows the circuit to generate the signals for both electrodes.

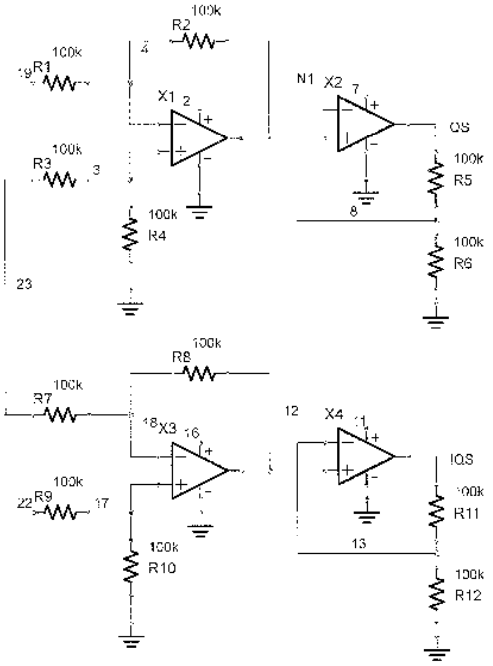

Fig. 5 Schematic of the control signal conditioning to drive electrode QS and !QS

As it was already mentioned the control signal is between 0 V and 4.096 V. This means that every value higher than 2.048 V feeds electrode QS and a value below this middle reference voltage controls electrode !QS. For this reason the reference voltage is applied to node 19 and 22, while the signal is applied to node 23. The input signal is halved by a resistor divider and fed to the positive input of operational amplifier X1. The reference signal is then subtracted from the input signal. As long as the signal level is below the reference level, the output remains 0 V because the amplifier is only supplied in an asymmetrical manner. The electrometer amplifier stage at the output amplifies the signal by the factor two again to achieve signal levels as high as 4.096V. If the level is higher than the reference a positive output voltage appears at X1 which is gained by X2 with the factor of two. This signal is used to drive electrode QS. If in opposite the signal is fed to the subtracting amplifier stage built up by X3, every signal below the reference level leads to a positive output signal of X3 because this lower value is subtracted from the reference at the positive input. Again the signal is amplified by the factor of two to achieve values as high as 4.096 V to drive electrode !QS. Important in both cases is that the operational amplifiers X1 to X4 have rail-to-rail inputs and outputs, to perform the ability to achieve 0 V levels. Figure 6 shows the simulation results of the described control circuit. The simulation was done with the B²Spice A/D V 5.2.3 of the company Beige Bag Software[1].

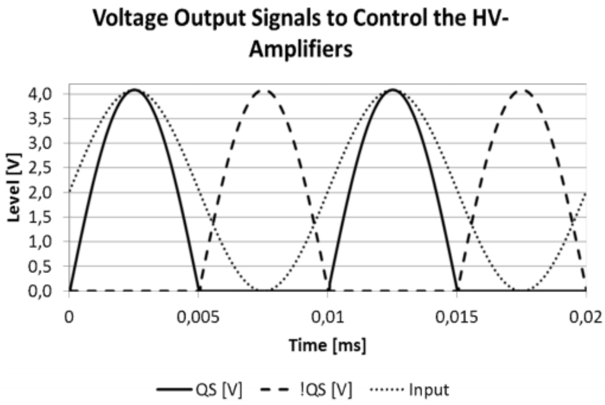

Fig. 6 Simulation result of the signal conditioning circuit to drive the quasistatic electrodes

Both – the modulated resonant signal and the conditioned quasistatic control signal are fed to the high voltage amplifier that gains the signals by the factor of 50, leading to an absolute maximal output voltage of 204.8 V. Figure 7 shows the block diagram of one integrated amplifier stage of the high voltage amplifier HV254 from the company supertex [11] that was used to realize this project.

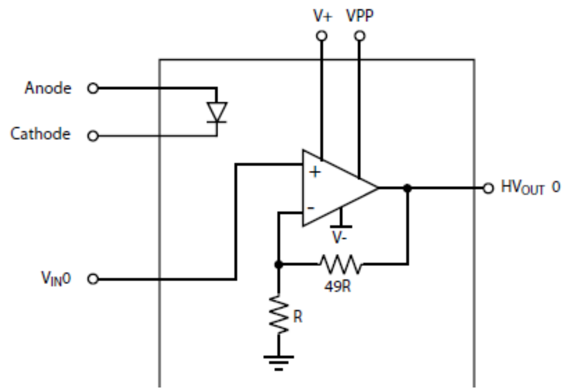

Fig. 7 Circuit of one stage of the 32 channel integrated high voltage amplifier chip

IV. MEASUREMENT RESULTS

The driver electronic was tested in a great detail. Some results are shown in the following figures. The first measurements show the characterization of the modulation stage to drive the resonant axis of the mirror device, while the second part illustrates the driver for the quasistatic one.

If a rectangular signal waveform with a high slew rate is applied to the input of the driver, the output signal shows the amplified signal but with a much lower slew rate. Referring to the measurement shown in figure 8 to 10 the rise and fall time increases to about 17 µs, resulting in a slew rate of approximately 11.5 V/µs.

[1] www.beigebag.com

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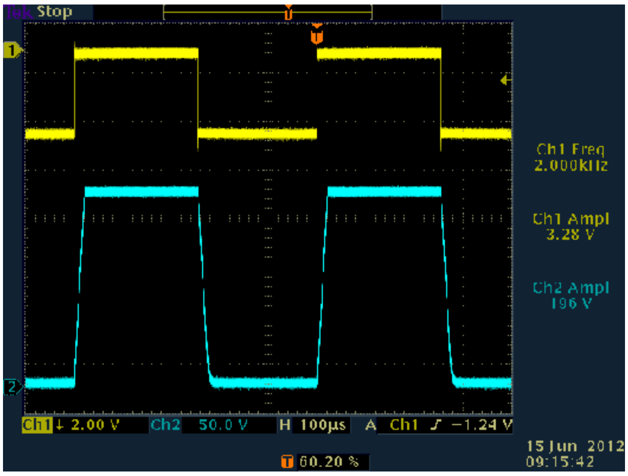

Fig. 8 Signal 1 shows the LVTTL input signal that was applied to the driver circuit and signal 2 illustrates the output HV level signal

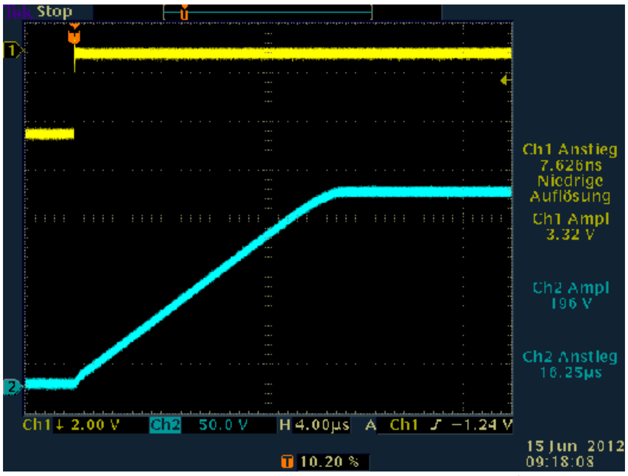

Fig. 9 Signal 1 shows the LVTTL input signal with its fast slope, while signal 2 illustrates the high voltage output signal with a rise time that is much longer

If the measurement result in figure 9 is investigated in more detail it can be seen that if the signal is switched on a small step of about 7 V occurs, which is design dependent. With the internal gain set at 50 V/V, a minimum input signal of 140 mV will still maintain linearity. Input voltages below 140 mV can be applied without damage but the amplifier will be saturated.

Figure 10 shows the fall time of the high voltage driver stage. The fall time is a little longer than the rise time influenced by the output stage of the amplifier circuit. If summing up the rise time, the fall time and for example a stable voltage of up to 20 µs a highest switching frequency with a duty-cycle of 50% of approximately 10 kHz can be achieved. When using the driver box for MOEMS devices, frequencies below 2 kHz on the resonant and lower 50 Hz on the quasistatic axes will be sufficient and can be achieved with good quality by this driver design without any problem.

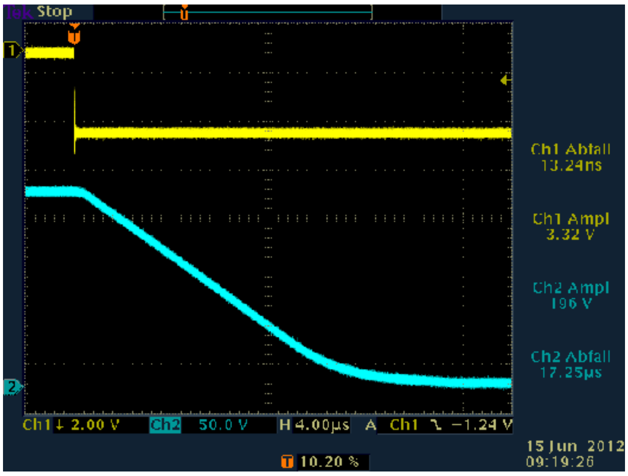

Fig. 10 Signal 1 shows the LVTTL input signal with its fast slope if being switched off, while signal 2 illustrates the high voltage output signal with a fall time that is much longer

Figure 11 represents the measurement result for the quasistatic driver that was first simulated in figure 5. Additionally the difference between both high voltage signals for both quasistatic axes was calculated on the oscilloscope to verify the overall output signal quality.

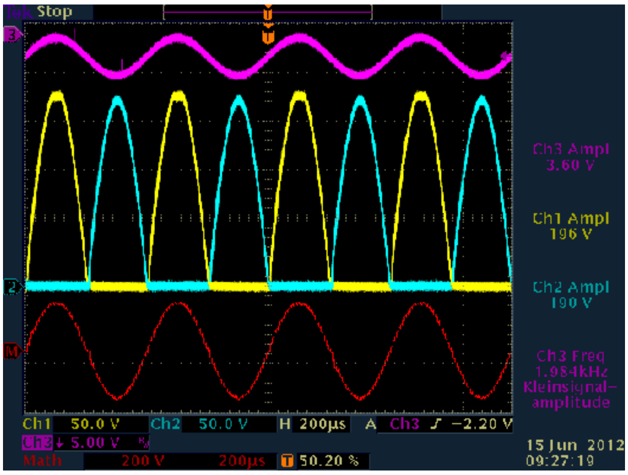

Fig. 11 Signal 3 is the DAC output and input for the driver, signal 1 and 2 that are overlapping show the two high voltage output channels and signal M represents the difference of signal 1 minus signal 2

At last a MOEMS mirror device was connected to the driver circuit and the characteristic of the device was measured. The result shown in figure 12 was done by increasing the voltage linearly within the specification of the MOEMS device.

An important fact is that the mirror movement starts at voltages higher than 10 V. This means that the step offset of approximately 7 V of the integrated driver does not have any effect on the mirror movement. Also any noise lower than this level will not have any effect, so the MOEMS mirror can be driven in a very robust way.

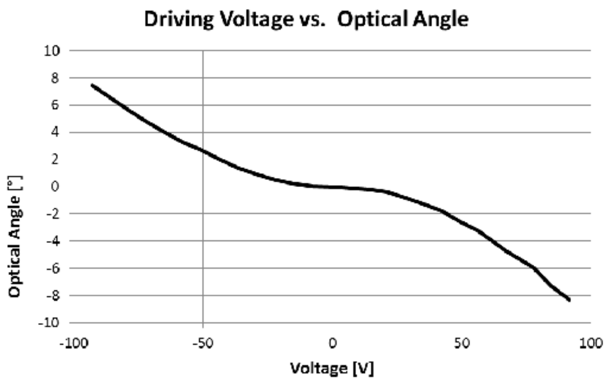

Fig. 12 MOEMS mirror movement as a function of a linear high voltage ramp. The result of each axis itself was combined in one EXCEL diagram so a voltage swing between ±95 V appears, whereat the driving scheme correspond to the one shown in figure 10

V. Conclusion

A smart high voltage MOEMS driver box was developed that enables the possibility to control up to six mirror devices, which have resonant and quasistatic axes. Also if this development was designed for a specific project it can easily be used for driving all kind of electrostatic MEMS devices. Great flexibility is assured because of the use of microcontrollers for each axis driver and also because of the implementation of an FPGA module.

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