PICOSCALE displacement measurements with low output power using an optical switch

INTRODUCTION

The **PICO**SCALE *Interferometer* is a powerful device for highly accurate displacement measurements. Based on a Michelson interferometer, the extremely compact sensor heads can be integrated in many setups even with strict space constraints such as vacuum chambers or cryostats. Especially for the latter, it is crucial to introduce as little electrical power as possible to the experimental setups and active electronics should be reduced to an absolute minimum. Optical displacement measurements thus are an attractive method to perform displacement measurements in cryogenic environments.
Compared to other techniques, the Michelson interferometer working principle is advantageous as highly reflective targets can be used without sophisticated considerations and drawbacks, so that only negligible amounts of optical power is absorbed in the target material. However, also low-reflective targets can be used (e.g. silicon wafers) with the **PICO**SCALE. In this case some part of the optical power is absorbed in the target material. To address this point, the very flexibly architecture of the **PICO**SCALE allows to connect an external optical switch blocking the laser light most of the time. Thus, the average power brought into the system via the sensor heads is significantly reduced. At the same time, the **PICO**SCALE *Interferometer* is triggered with the same switch pulses in order to only perform position measurements only when the switch does **not** block the light. (Otherwise the internal real-time position calculation would try to infer displacement data from noise and result in invalid data.)
In the following we demonstrate an overview on the experimental setup and show that the average output power can be reduced by more than two orders of magnitude to about 1 µW.

EXPERIMENTAL SETUP

The experimental setup is illustrated in Figure 1. An optical switch (*Nano Speed 1x2 Switch* from AGILTRON and appropriate driver board) is connected to one channel of a **PICO**SCALE Interferometer. The electrical signals driving the switch are generated in the Controller by using the *Clock Generator* Firmware Module and the GPIO interface. The latter can conveniently be accessed via the **PICO**SCALE *Breakout Box*. For details on the generation and processing of these pulses please refer to Figure .

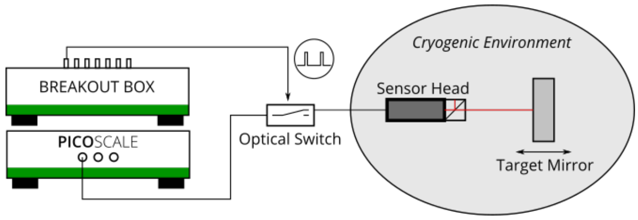

Figure 1. *Experimental setup. An optical switch is introduced to one channel of the interferometer and driven with TTL signals generated by the* **PICO**SCALE *Controller. The same pulses are used internally to trigger the position calculation.*

SIGNAL PROCESSING

The switch is driven with TTL pulses at a frequency of 10 kHz with a very low duty cycle (below 1 %). These signals are generated in the **PICO**SCALE Controller using two instances of the *Clock Generator* module which are phase shifted by 179° and logically combined with an AND operation, cf. Figure . The output signal is shown in Figure 2.

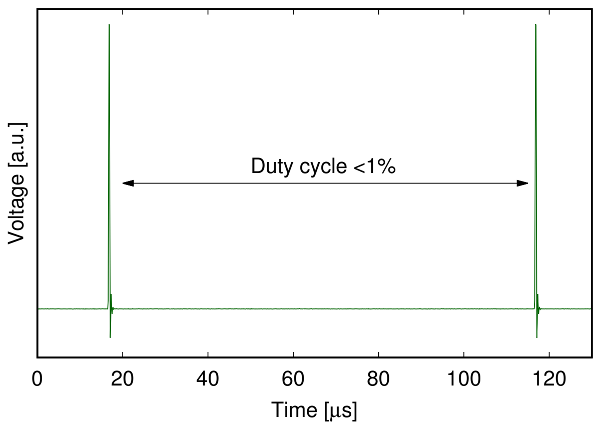

Figure 2. *Output signal of the Breakout Box driving the optical switch. The duty cycle is below 1 %.*

At the same time, the position calculation of the **PICO**SCALE is triggered by the rising edge of one of the two clocks. A tiny delay of 4.5 µs is introduced to this trigger to account for optical and electronic delays in the switch. A block diagram of the signals used is shown in Figure 4.

RESULTS

The optical power through the switch is measured with a power meter. As this device has a relatively low bandwidth, the output power is averaged over time. Due to the very small duty cycle it is reduced by more than two orders of magnitude, as shown in Table 1.

Table 1. *(Averaged) optical output power of the switch*

Switch state	Output power
Off	240 μW
On	<1.5 μW

To show that the quality of the data does not suffer, a proof-of-principle experiment was performed. A **PICO**SCALE sensor head was aligned to a target mirror while the base plate of the setup was heated slowly. The thermal drift is then tracked with the **PICO**SCALE displacement measurement. The position signal is shown in Figure 3. No difference in the signal-to-noise ratio is visible when the switch is activated and blocking the laser light for more than 99 % of the time.
It should be noted, that due to the switching the maximum speed of the target is limited, as the target should be tracked with a data points at least every ≈200 nm. The resulting maximum target speed is thus given by

$$\begin{aligned} v_{max} &= 200\,\text{nm} \cdot \text{switch frequency} \\ &= 200\,\text{nm} \cdot 10\,\text{kHz} \\ &= 2\,\text{mm}\,\text{s}^{-1} \end{aligned} \tag{1}$$

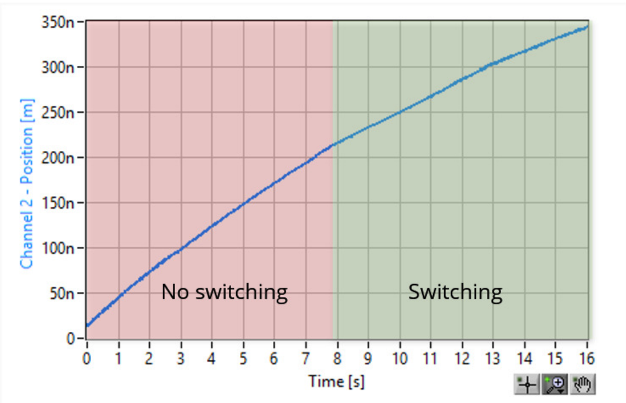

Figure 3. *Displacement measurement with and without switching off the laser light. When the switch is on (right hand side), it is blocking the laser light for more than 99 % of the time.*

CONCLUSION

We have shown that the output power of the **PICO**SCALE Interferometer can be reduced to the single micro-watt level with an optical switch. The signal-to-noise ratio and thus the quality of the data do not suffer, as the position calculation is triggered and using signals that are resulting from measurements with maximum output power. This feature may enable closed-loop positioning in cryogenic environments, where the total power should be reduced to a minimum.
As all signal are generated within the controller, no external devices except the optical switch and its driver are required. This fact once more emphasizes the devices versatility to be linked with a great variety of other laboratory equipment.

RELATED APPLICATIONS

Please also see Application Note AN00015 [1], where the **PICO**SCALE *Interferometer* has been used with an optical chopper.
Please also see a related publication [2], where the **PICO**SCALE *Interferometer* was used with chopped beam.

REFERENCES

[1] SmarAct. PICOSCALE interferometer with chopped measurement beam. *SmarAct Application Note*, May 2019.

[2] Wolfgang Schweinberger, Lenard Vamos, Jia Xu, Syed A. Hussain, Christoph Baune, Sebastian Rode, and Ioachim Pupeza. Interferometric delay tracking for low-noise Mach-Zehnder-type scanning measurements. *Opt. Express*, 27(4):4789–4798, Feb 2019.

SIGNALS

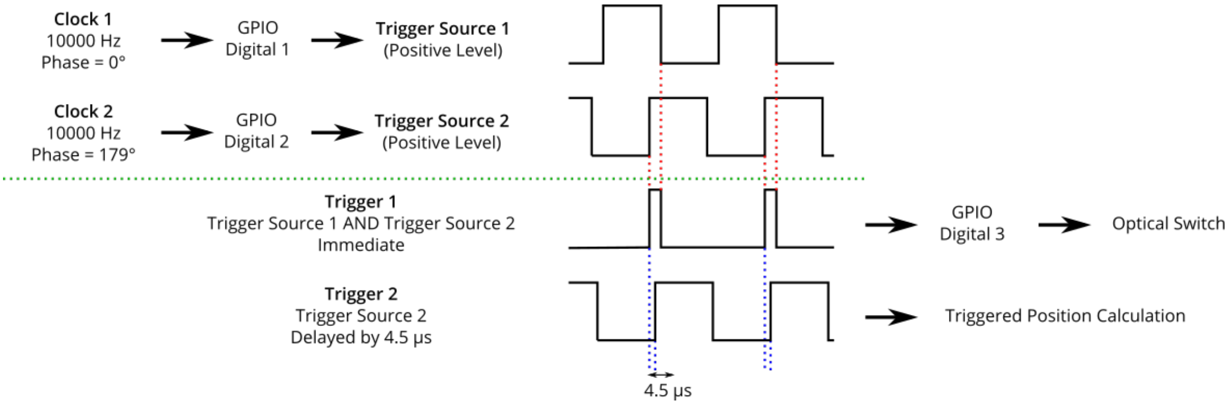

Figure 4. *Configuration of the internal signals. Two instances of the Clock Generator firmware module are generating clock signals at 10 kHz with a relative phase shift of 179°. Each of them is mapped to a digital GPIO pin so that it can be used within the Advanced Trigger firmware module. Two trigger sources are configured to mirror the clocks. One trigger is then configured to produce an output using the logical AND operation of the two trigger sources. This trigger is subsequently output via a digital GPIO pin to be used for the optical switch. A second trigger is configured using the second trigger source. It is delayed by 4.5 µs to compensate various electronic and optical delays. Ultimately, its rising edge is used to trigger the position calculation of the* **PICO**SCALE.

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