# PICOSCALE Interferometer Noise and Resolution

**Abstract**
The **PICO**SCALE is a measurement device based on a Michelson interferometer. The signal noise of an interferometer is an important performance benchmark. This document demonstrates that the **PICO**SCALE interferometer achieves a noise level in the sub-picometer region.

## 1. EXPERIMENTAL PROCEDURE

In order to determine the noise floor of the **PICO**SCALE, a sensor head is adjusted to a plane target mirror at 20 mm distance. The setup is mounted inside an enclosure in order to suppress perturbations by thermal expansion and air fluctuations. The setup is mechanically isolated by a foam pad and placed in a thermally stabilized environment (about 21.5 °C). The data shown in section 2 is obtained with the **PICO**SCALE GUI. Except shifting each data set by its mean value, no further post processing was done.

## 2. RESULTS AND DISCUSSION

The **PICO**SCALE provides a range of filter streaming rates. These parameters have are crucial with respect to the noise floor of the measurement and the signal-to-noise ratio.

### 2.1 Time domain measurements

A displacement measurement was performed with three different frame and corresponding filter rates (1.22 kHz, 39.06 kHz and 10 MHz). Figure 2 shows the distribution of 10000 data points of the position of the target for three different frame and filter rates. The time traces for sample frequencies of 1.22 kHz and 10 MHz are shown in Figure 1. If the filter rate is high, a higher spectral range is sampled and the data is accumulated to a more noisy trace.

It can be seen that the signal becomes less noisy with decreasing filter rate. This results from the decreasing cut-off frequency for lower filter rates so that a smaller specral range is sampled. The standard deviations for the distributions from Figure 2 are shown in Table 1.

| Filter rate | Standard deviation |
|---|---|
| 1.22 kHz | 70 pm |
| 39.06 kHz | 86 pm |
| 10 MHz | 399 pm |

***Table 1.*** *Standard deviations of the distributions of Figure 2.*

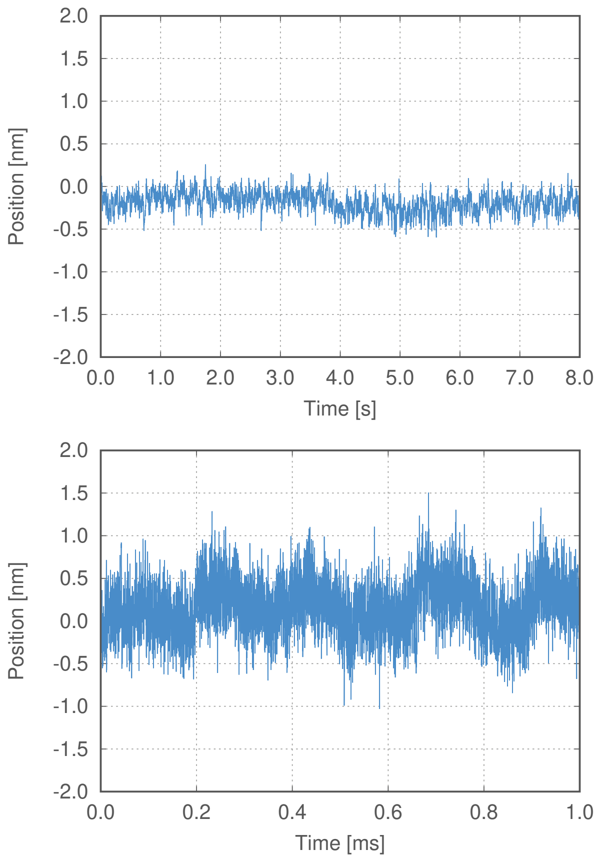


***Figure 1.*** ***Position*** *data (**left** column) for different filter rates measured at a working distance of 20 mm. **Top**: **1.22 kHz**. **Bottom**: **10 MHz**.*

### 2.2 Frequency domain measurements

The amplitude spectral density of the position signal is shown in Figure 3. It was recorded with a sample rate of 2.5 MHz.

#### 2.2.1 Influence of working distance

If the working distance increases, also the noise floor increases due to laser phase noise. This effect has been measured with four different working distances from 20 mm to 1.2 m. The noise floor at 1 kHz was evaluated. A linear fit reveals, that the noise floor increases with a slope of 0.058 pm mm$^{-1}$, cf. Figure 4.

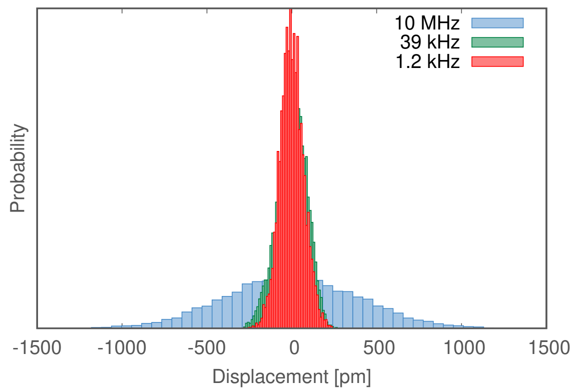


***Figure 2.*** *Normal distributions of the position signal at different filter rates. The small deviations between the Gaussian curves and the raw data is caused by the change of target mirror position as it can be seen in Figure 1.*

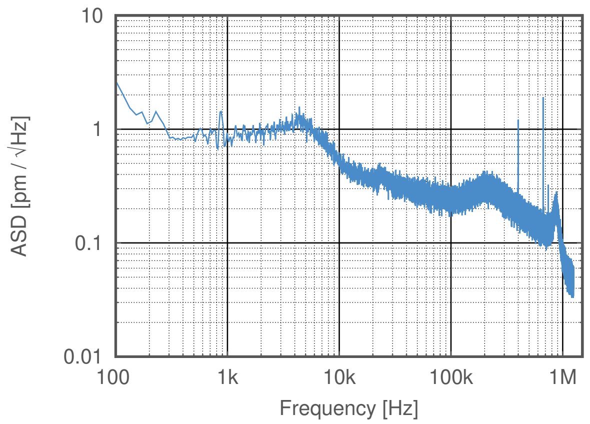


***Figure 3.*** *Amplitude spectral density of the position signal of a mirror at 20 mm working distance recorded with a sample rate of 2.5 MHz.*

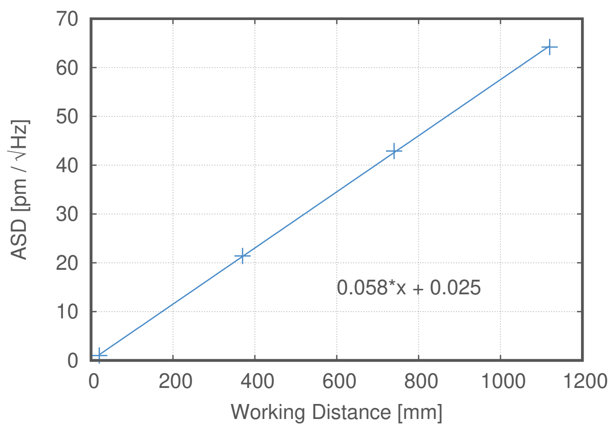


***Figure 4.*** *Noise floor at 1 kHz measured at different working distances. Due to laser phase noise, the noise floor increases linearly.*

## 3. CONCLUSION

It has been demonstrates that the **PICO**SCALE interferometer achieves a noise level in the sub-nanometer range. Regardless of the streaming frequency, the $\sigma$ width of the normal distributed noise is well below 1 nm. It has also been shown, that the noise floor does never exceed 10 pm/$\sqrt{\text{Hz}}$ for relevant filter rates above 100 Hz.

## 4. NOTE

If the **PICO**SCALE shall be operated at larger working distances and the increasing noise floor is problematic, SmarAct recommends to use differential sensor heads. Due to the Michelson principle, it is possible to also guide the reference beam of the interferometer externally so that the effective working distance can be kept very short. This will reduce the noise floor significantly, as shown in Figure 5. For details and discussion of the applicability of this technique please contact SmarAct.

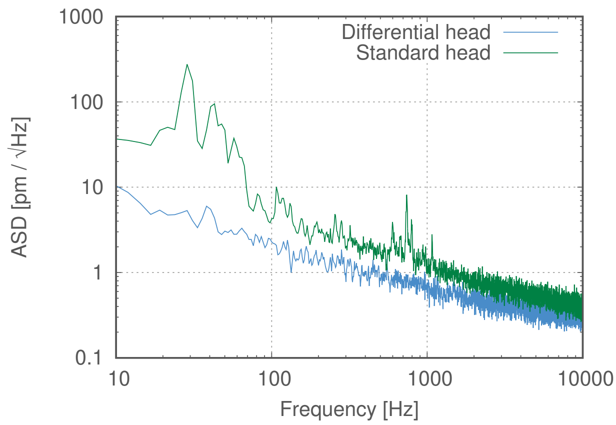


***Figure 5.*** *Comparison of the differential assembly with a standard sensor head at the same working distance. The differential assembly shows lower noise, especially at low frequencies, as the effective working distance is smaller and fluctuation in the ambient conditions are efficiently cancelled out.*

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