An accelerometer for spaceborne applications with interferometric readout: test of LIG performances

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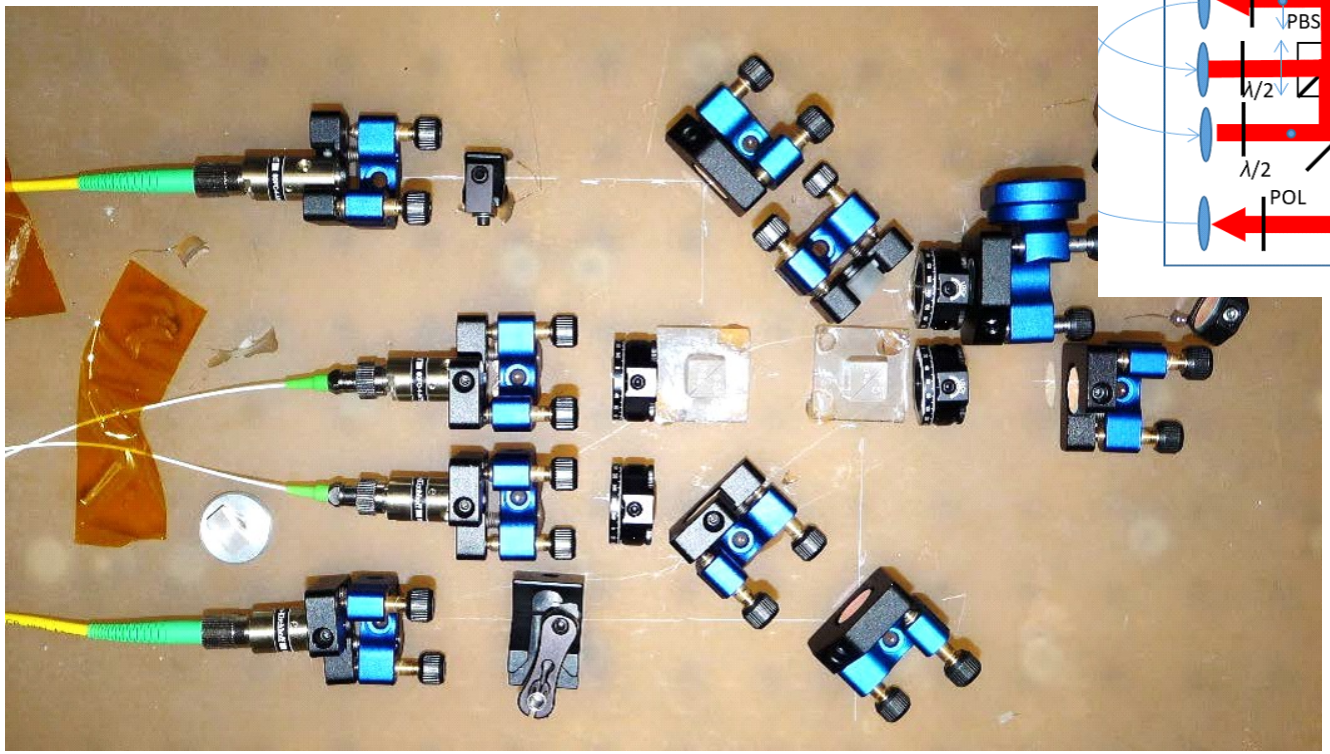
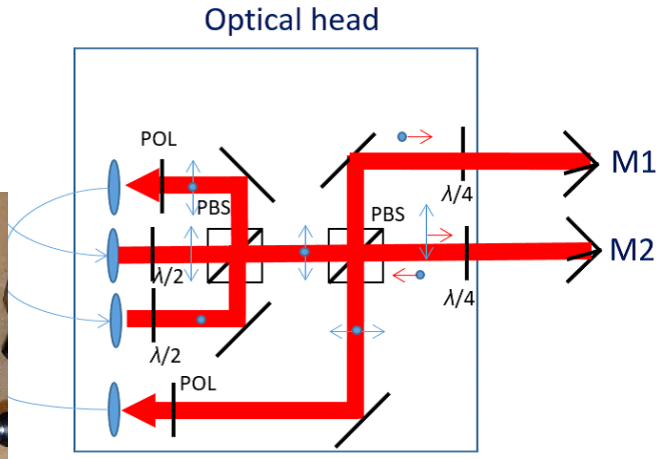
Test of the performances

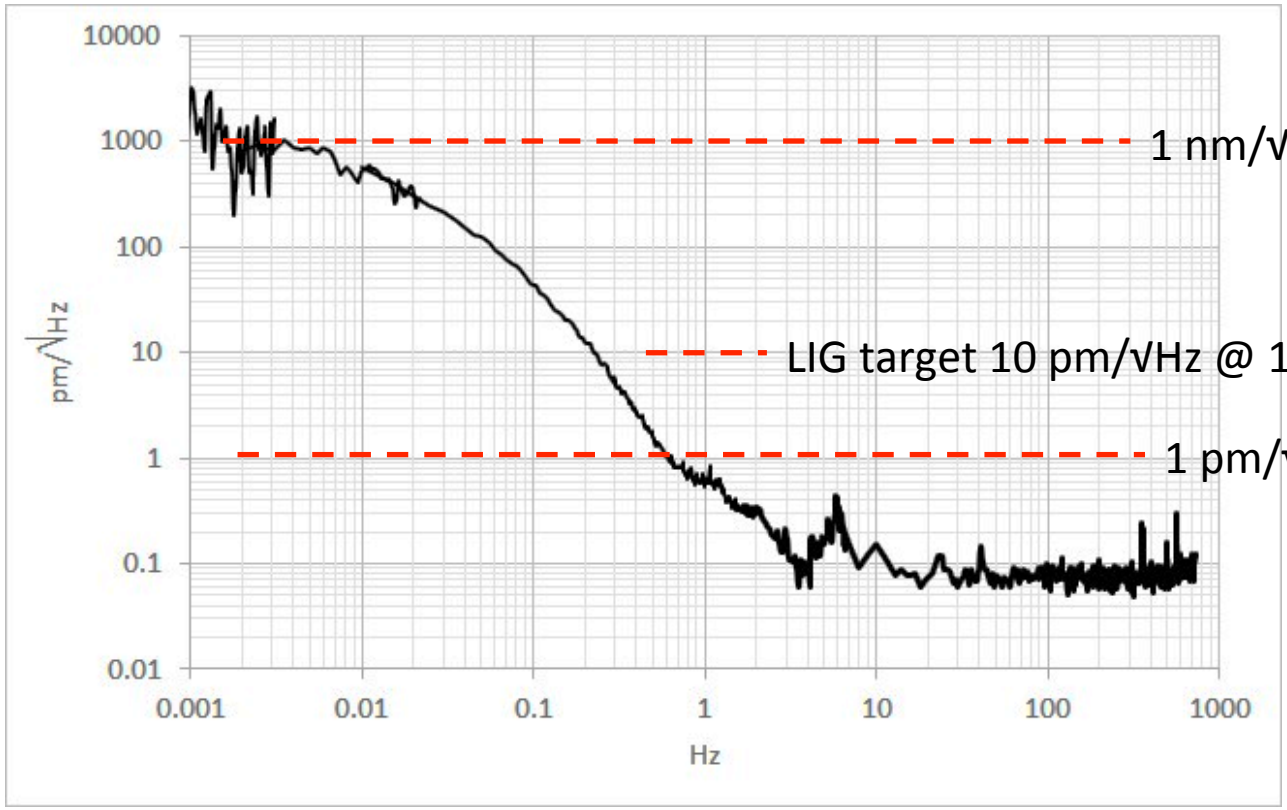
- Resolution/noise test
- Accuracy/non-linearity test

Resolution/noise test





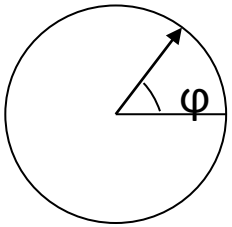
LIG displacement noise



How to measure the accuracy?

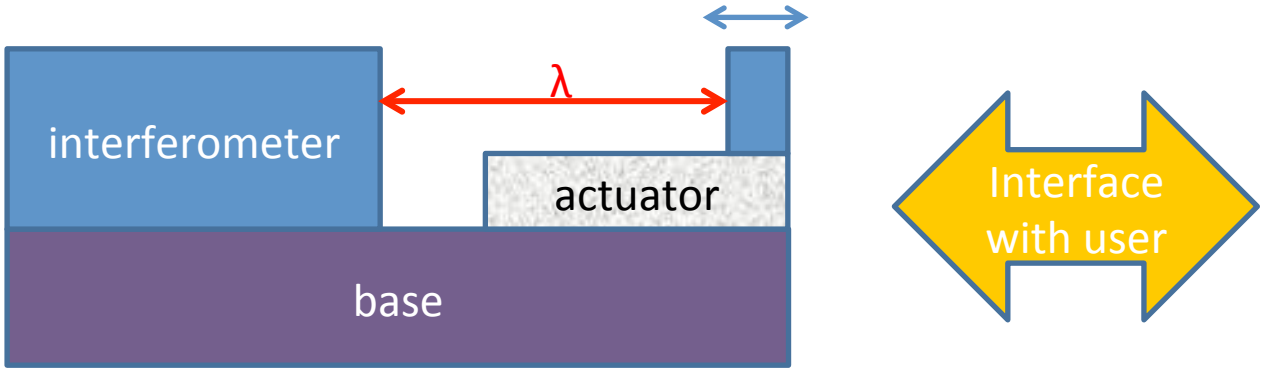
We need a super-linear super high resolution reference actuator!

We made it and called Pico Reference Actuator (PRA)

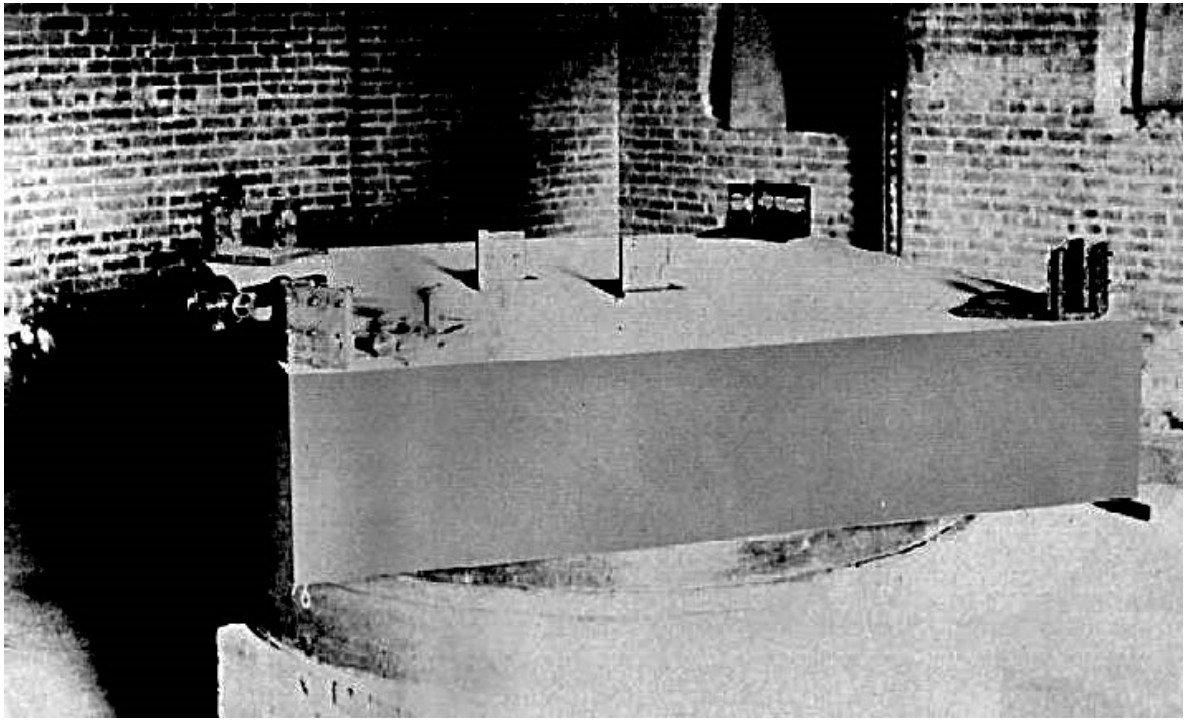


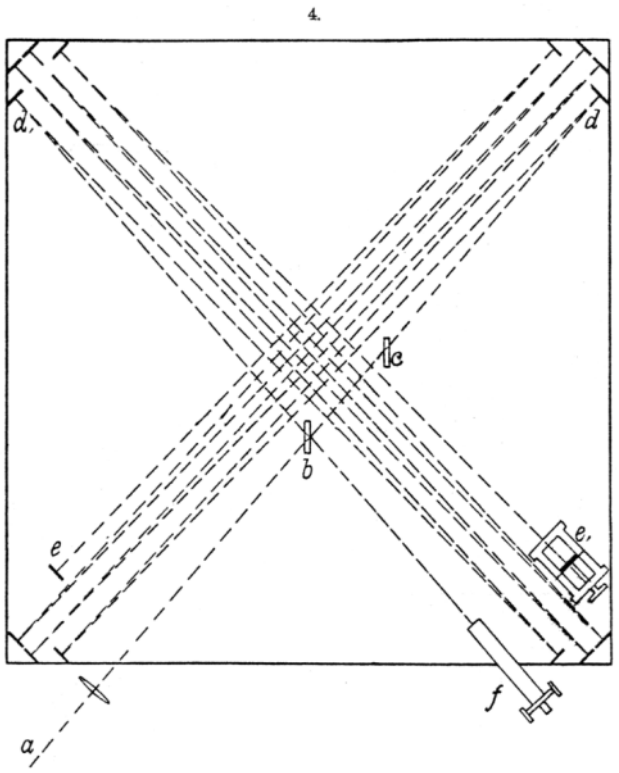
PRA working principle

Linear actuator + extremely high resolution interferometer

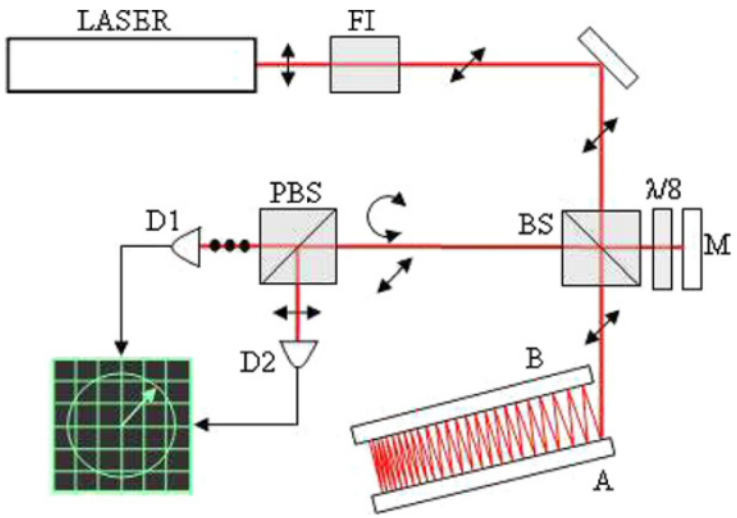


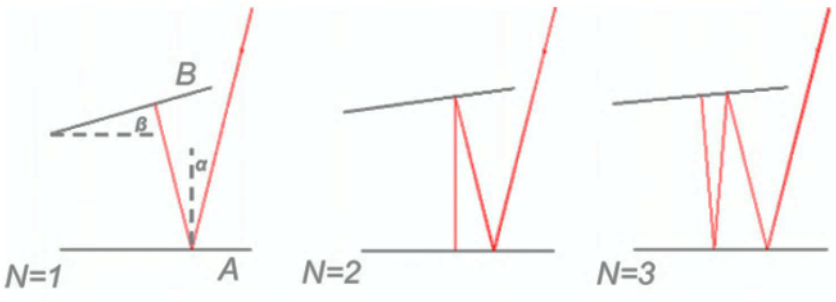
Multiple reflection set-up 1888





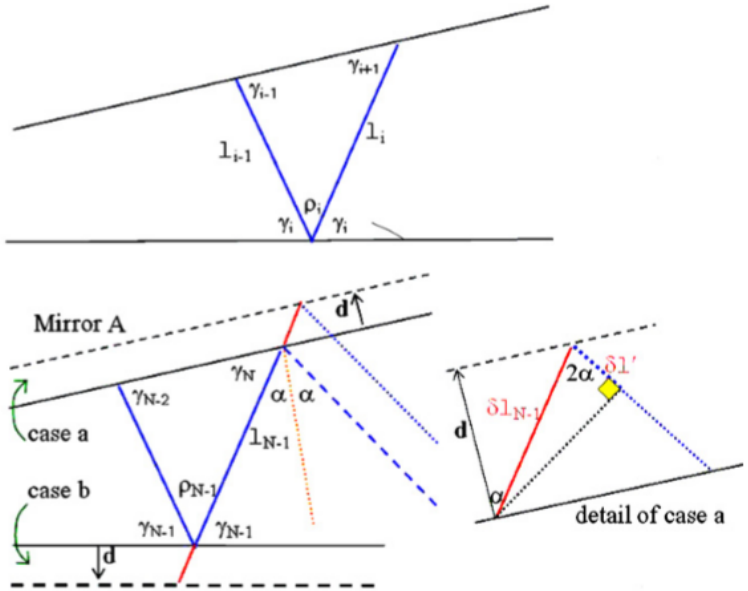
Multi-reflection interferometer





- The measurement beam of the interferometer is reflected N times between two mirrors
- The optical path change is the displacement multiplied by a factor N
- Almost true…

Correction parameter



$$\alpha = \rho_N/2 = N\beta. \tag{2}$$

From equation (1) we have that l_{N-1}, the length of the last path entirely contained between the two mirrors, is related to l_0 as follows:

$$l_{N-1} = l_0 s_1/(s_{N-1}s_N) \quad \text{or} \quad l_0 = l_{N-1}s_N/s_1. \tag{3}$$

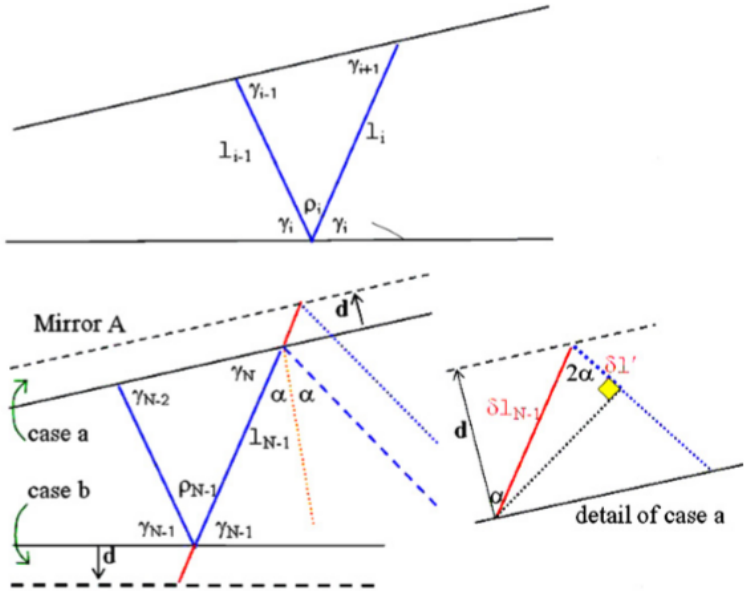
After defining

$$K(N,\alpha) = \sum_{i=0}^{N-1} 1/(s_i s_{i+1}), \tag{4}$$

we then have an exact expression for the total 'internal' pathlength L

$$\begin{aligned} L^{\text{int}} &= 2(l_0 + l_1 + l_2 + \cdots + l_{N-1}) \\ &= 2l_0 s_1 K = 2l_{N-1}s_{N-1}s_N K. \end{aligned} \tag{5}$$

Correction parameter



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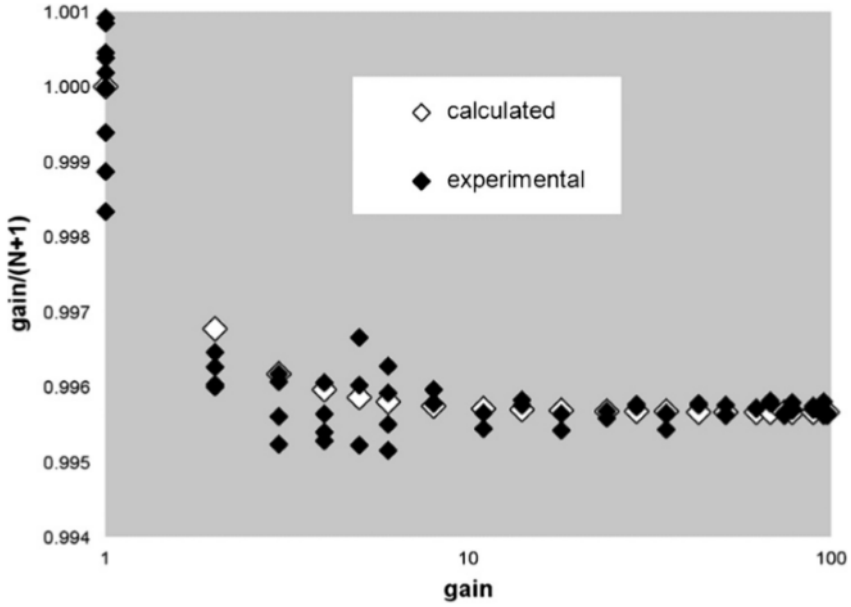
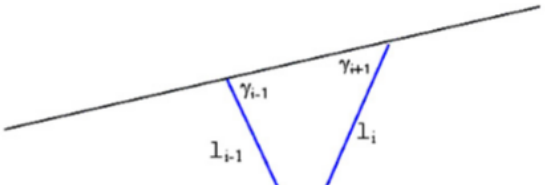
l_{N-}

After def

we then
pathlengt



Correction parameter



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A homodyne Michelson interferometer with sub-picometer resolution

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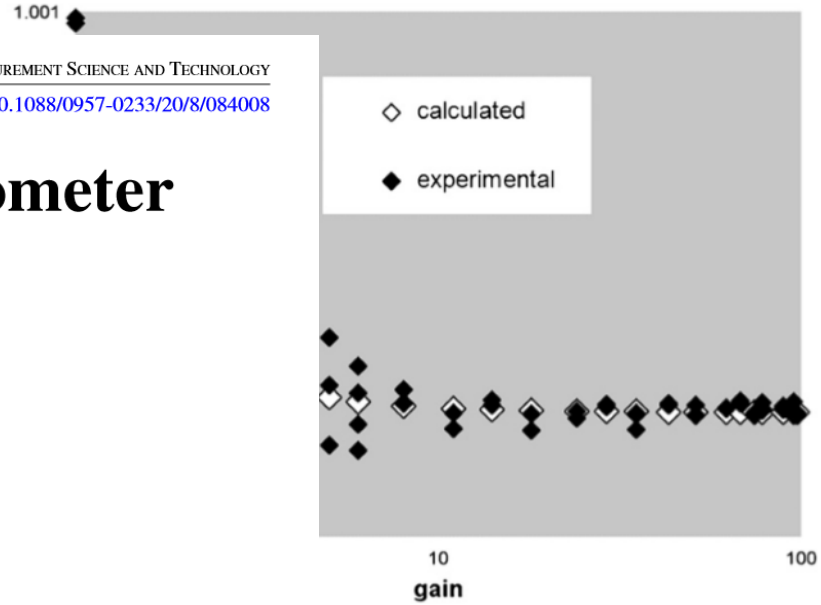
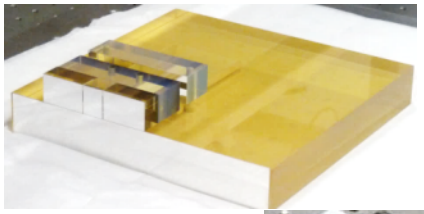
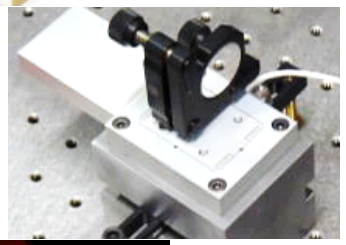
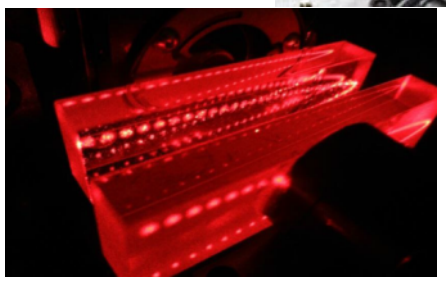


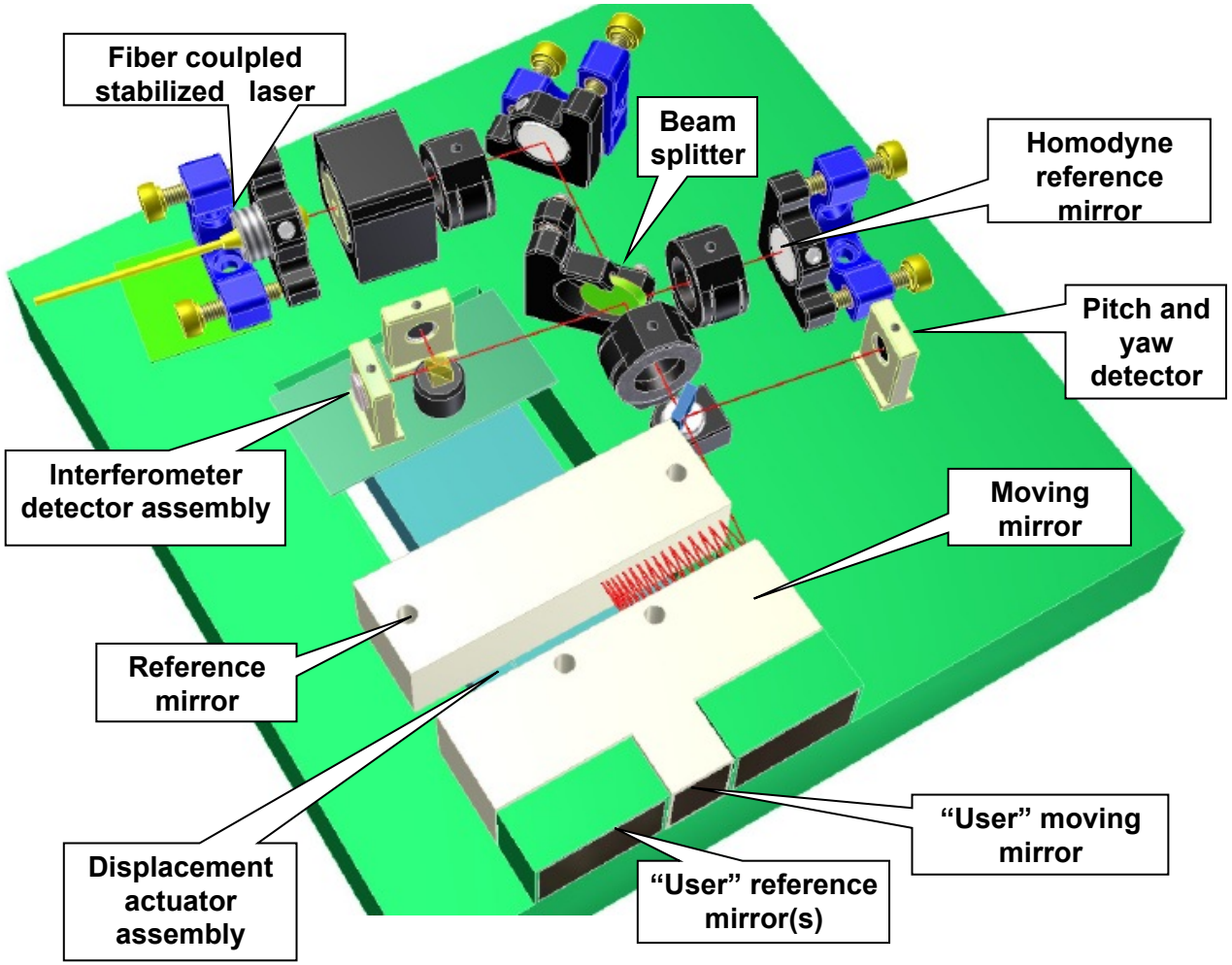
Practical realization

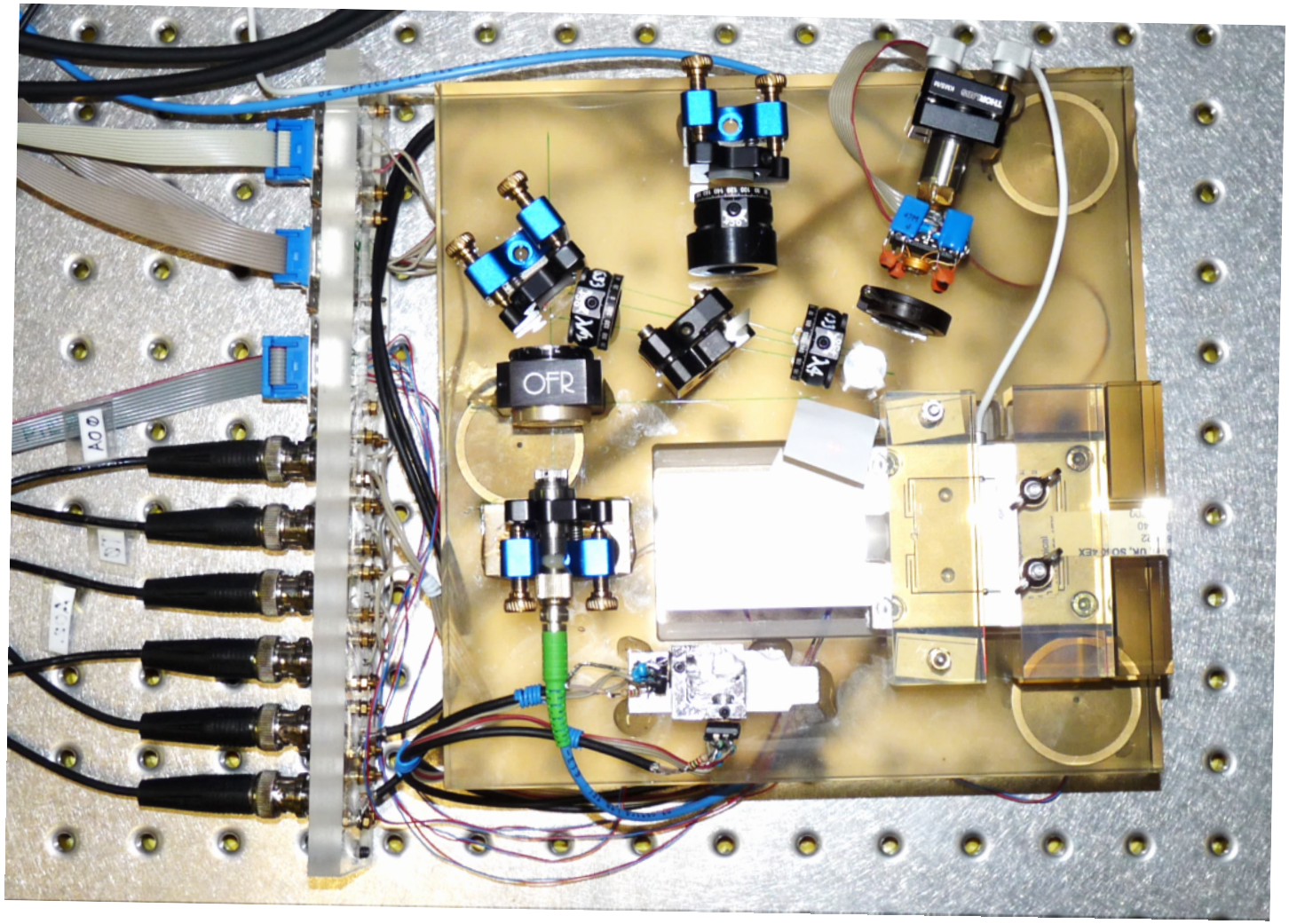
- The structure is made of Clearceram (low CTE)
- The actuator is a piezo driven fexure stage with 100 µm stroke and integrated metrology (MCL NanoOP100)
- Two high reflectivity (R>99.5%) mirrors as optical path multiplicator








Fiber coulpled stabilized laser
Beam splitter
Homodyne reference mirror
Pitch and yaw detector
Interferometer detector assembly
Moving mirror
Reference mirror
Displacement actuator assembly
"User" reference mirror(s)
"User" moving mirror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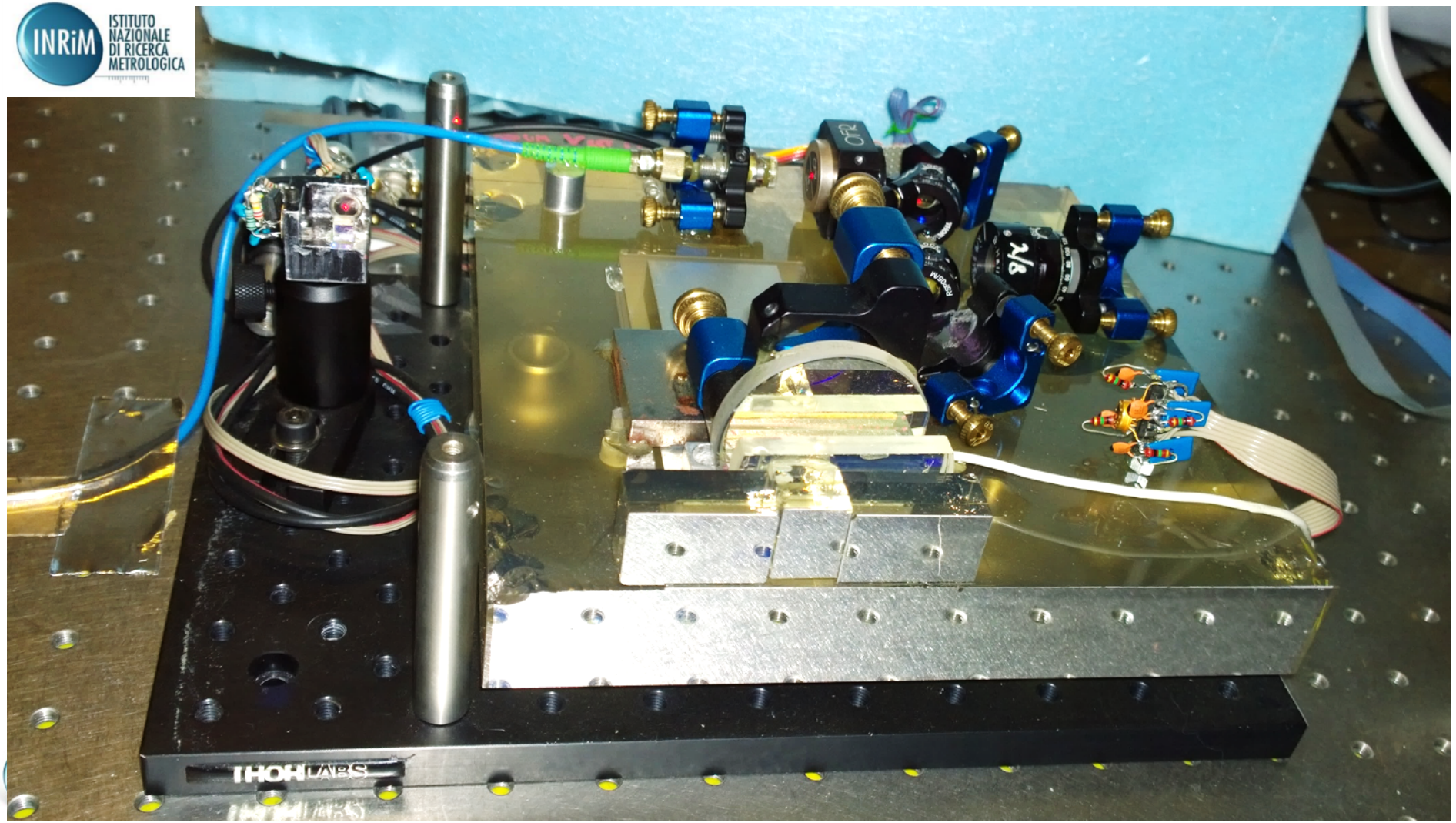
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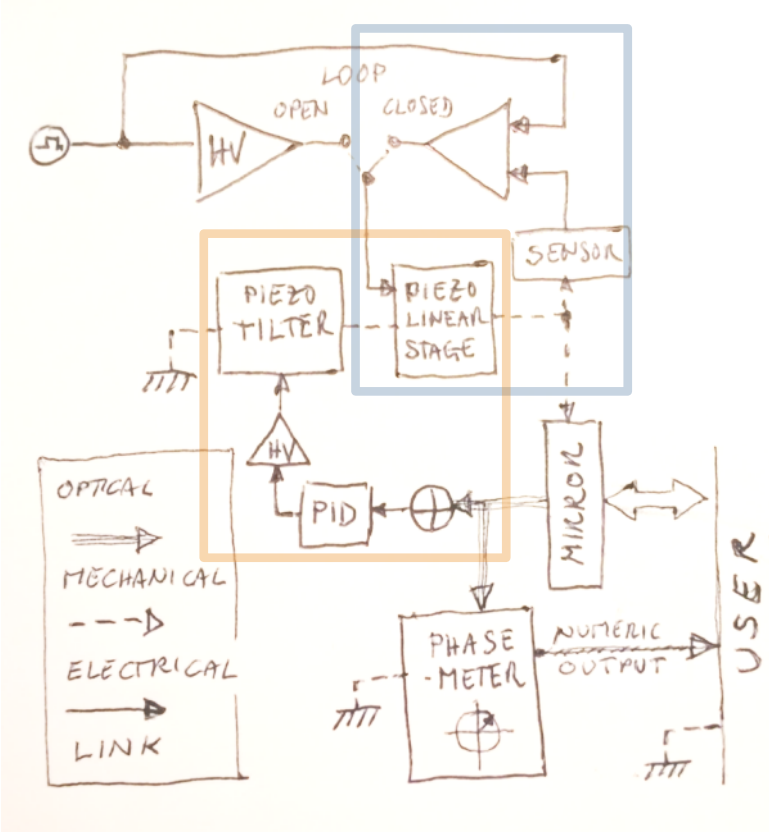
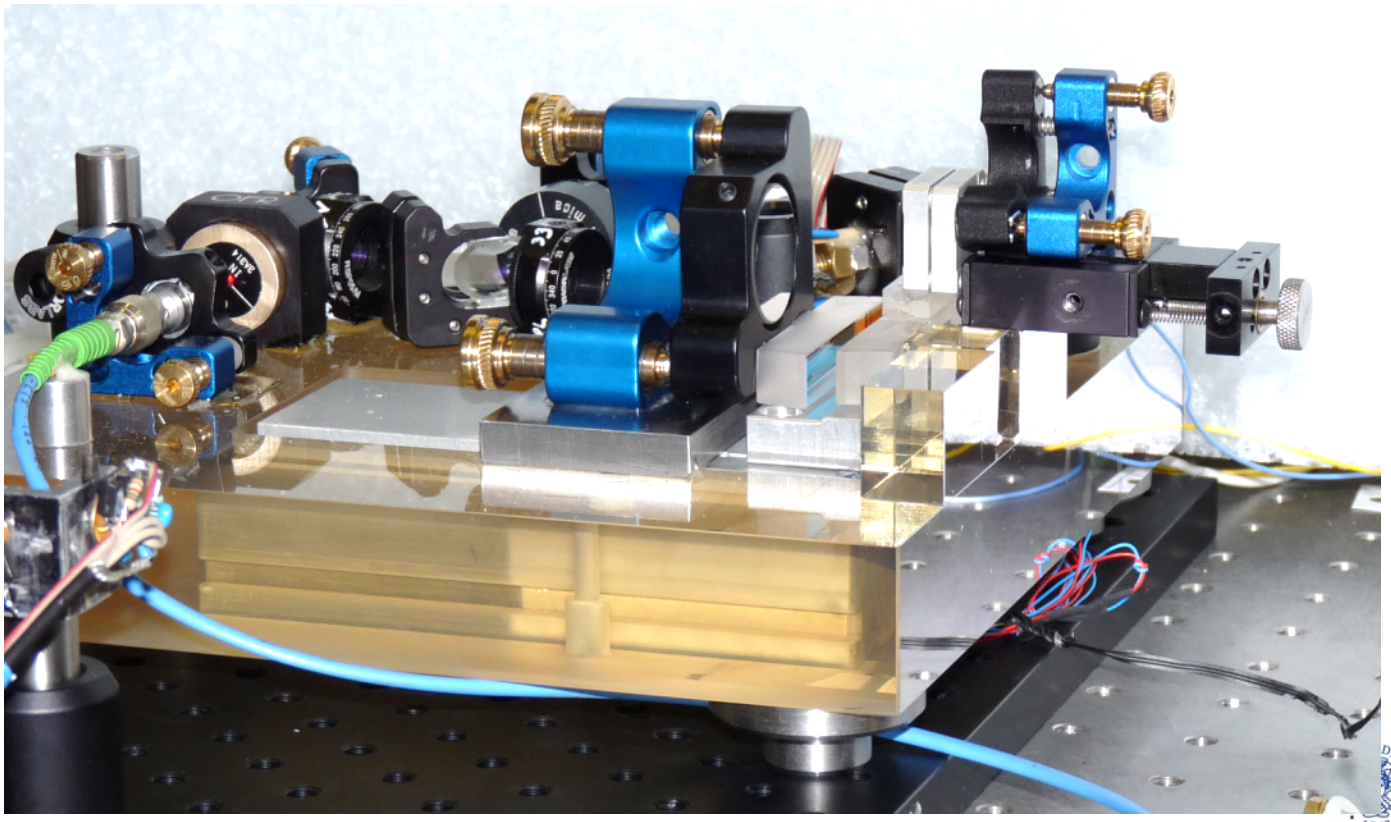
Opto-electro-mechanic simplified scheme

- Open loop: the piezo actuator is driven with a low noise voltage source with an «unknown» amplitude.
- Closed loop: the piezo actuator makes use of its own metrology system and is driven in a more deterministic way. More noisy.
- In both cases the output of the device is the interferometer reading.

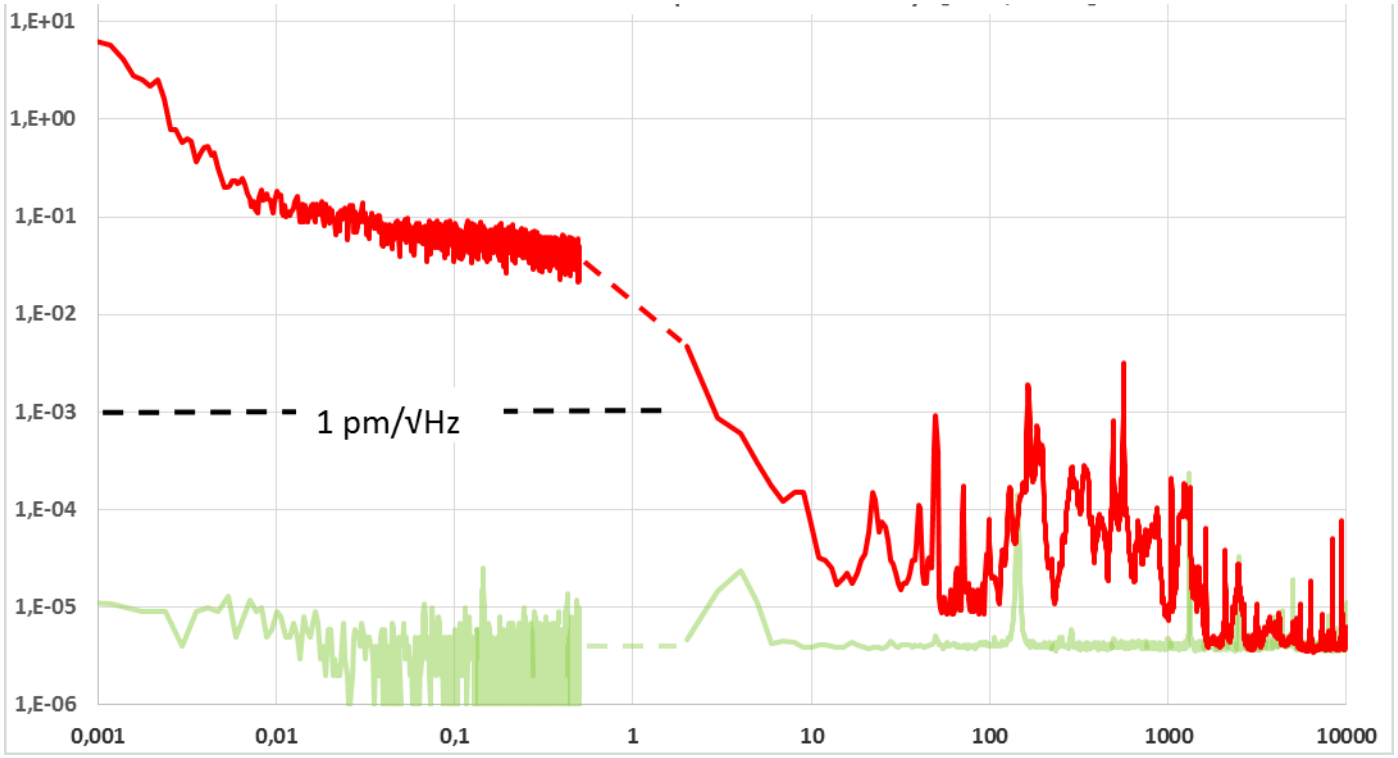


Example of application

Calibration of a capacitive sensor: one of the electrodes is glued to the moving mirror

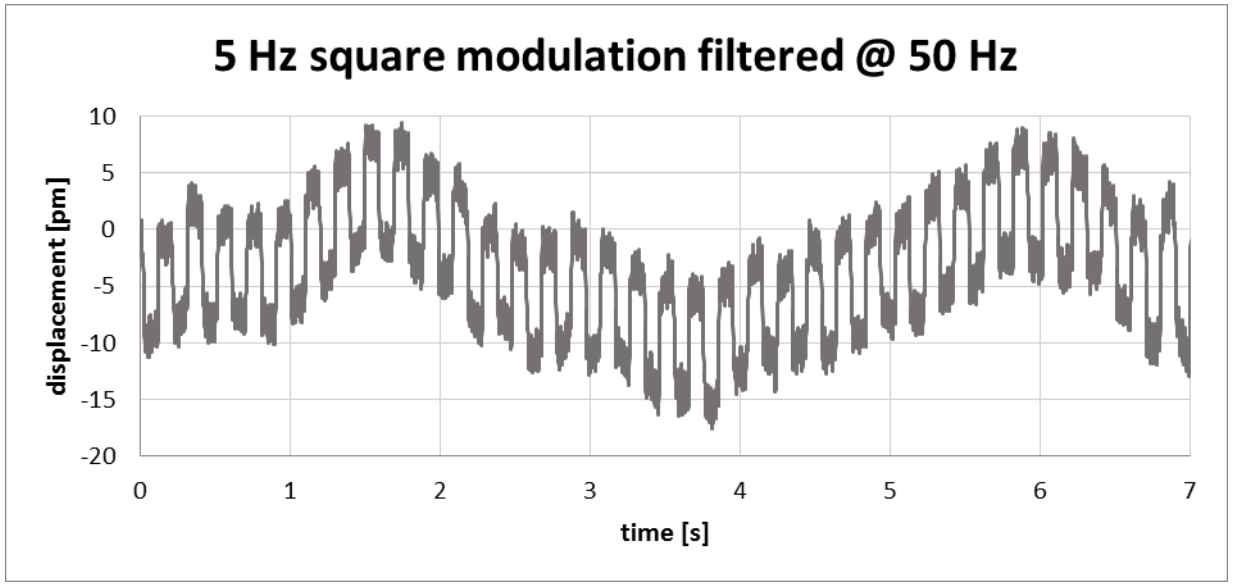


PRA displacement noise test (nm/√Hz)

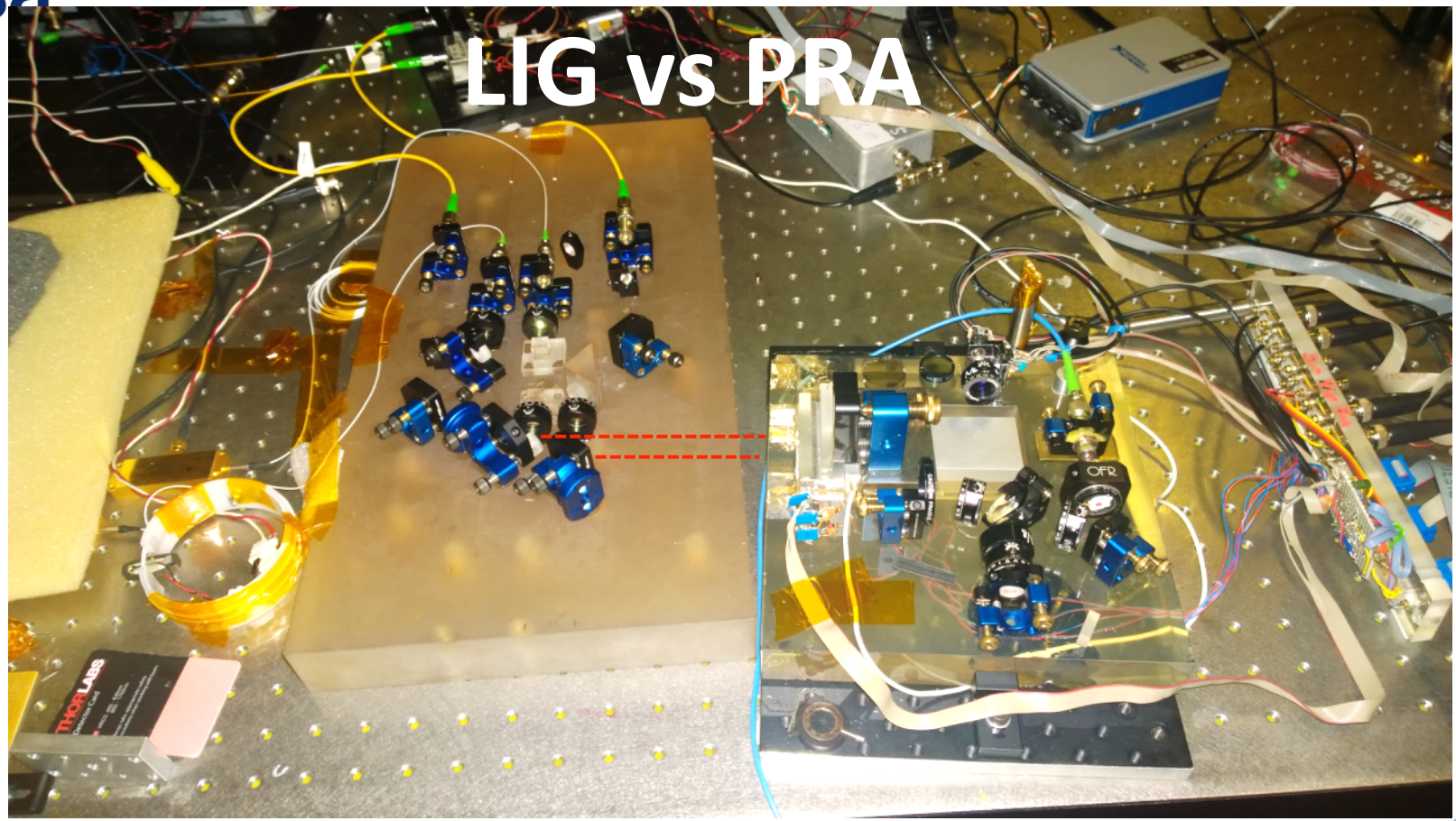


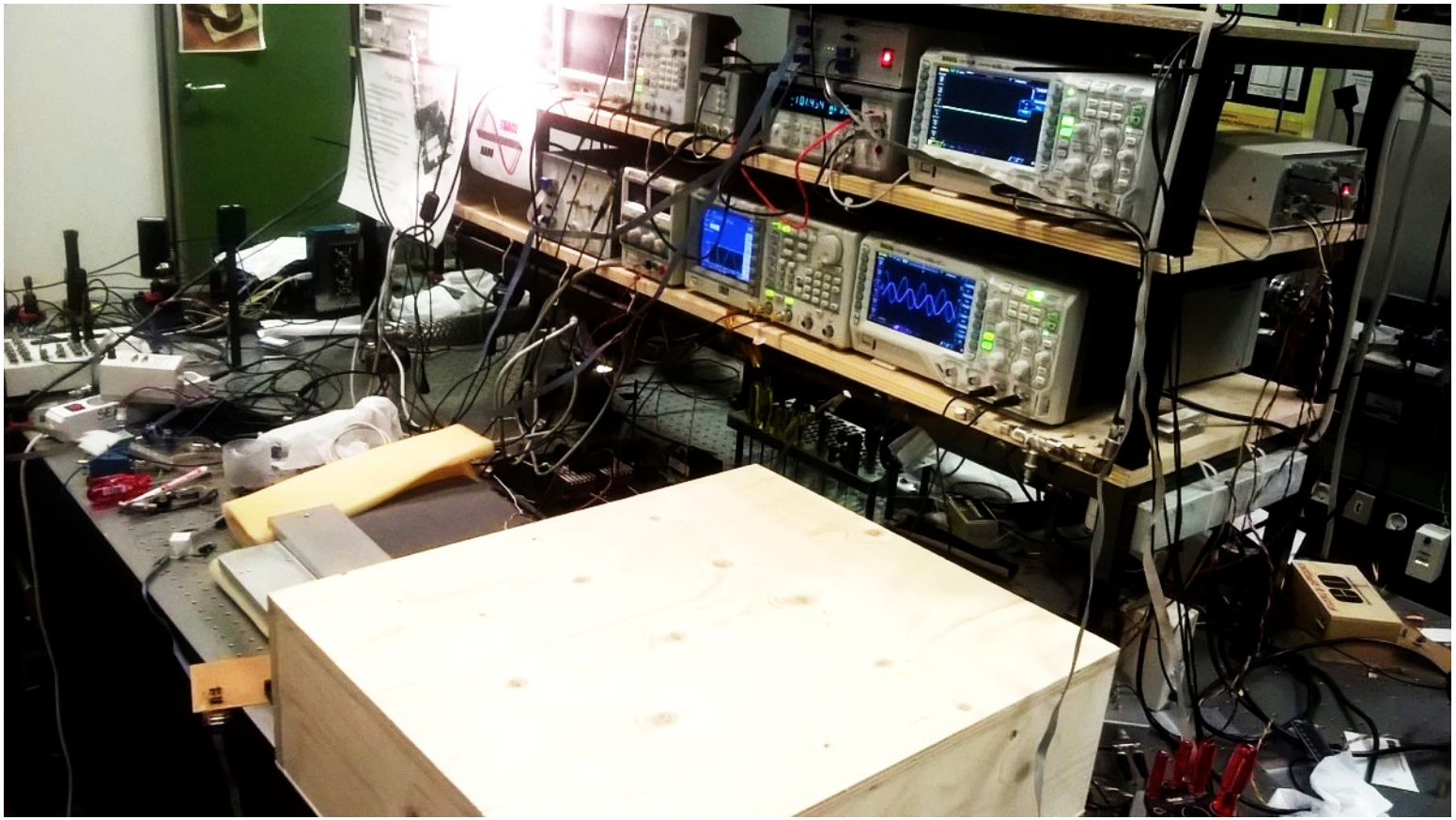
PRA resolution/noise test

10 pm p.p. = 10^{-7} of full range (about 10 µV p.p. to the piezo)

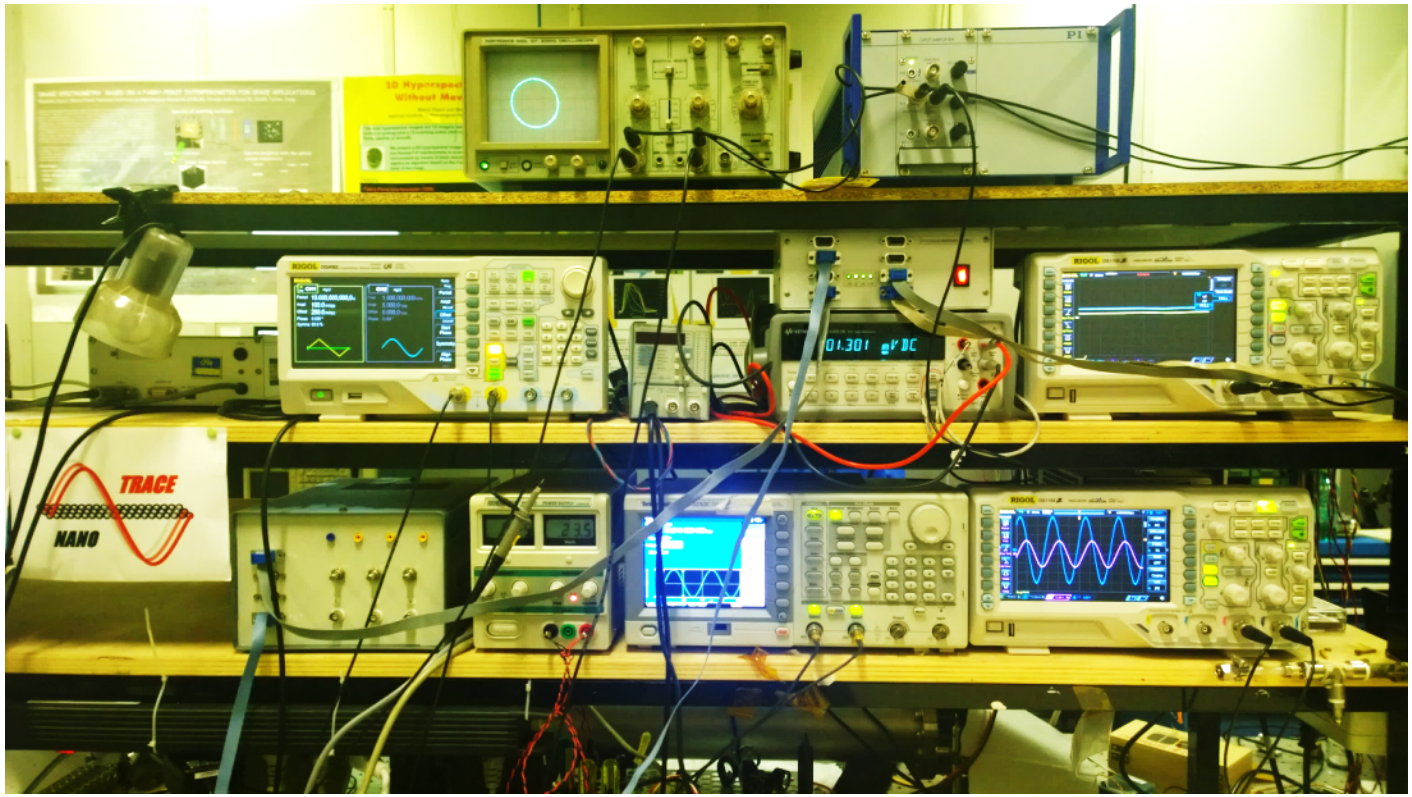


LIG vs PRA

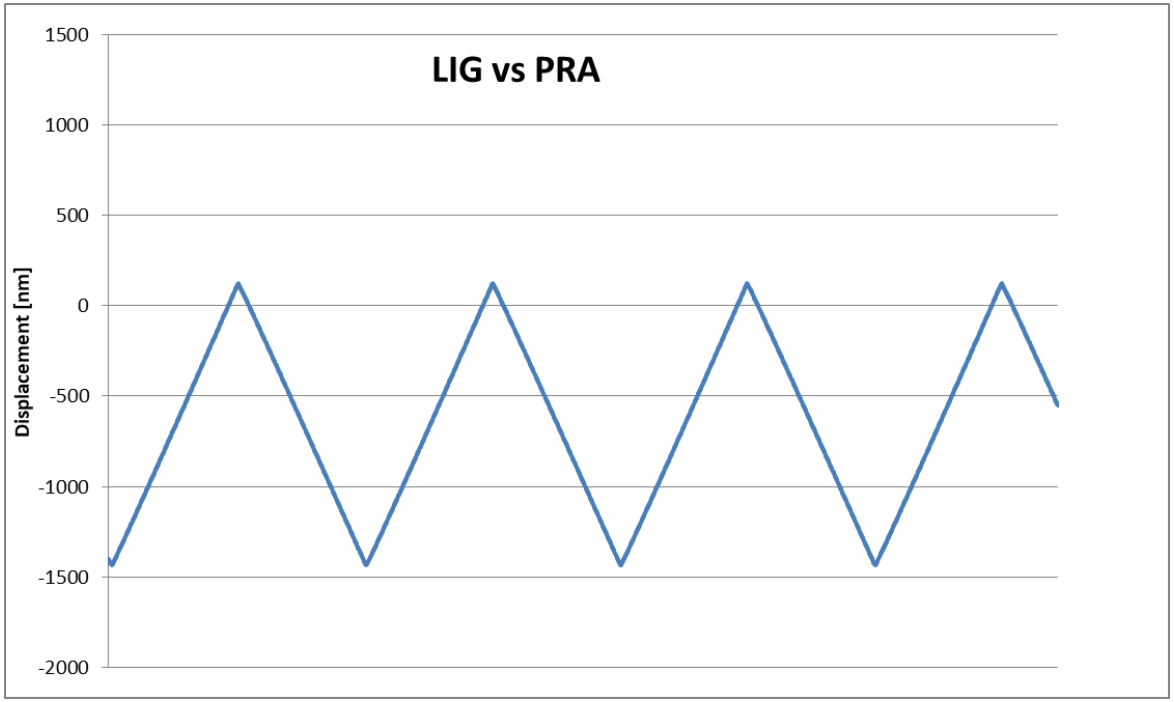




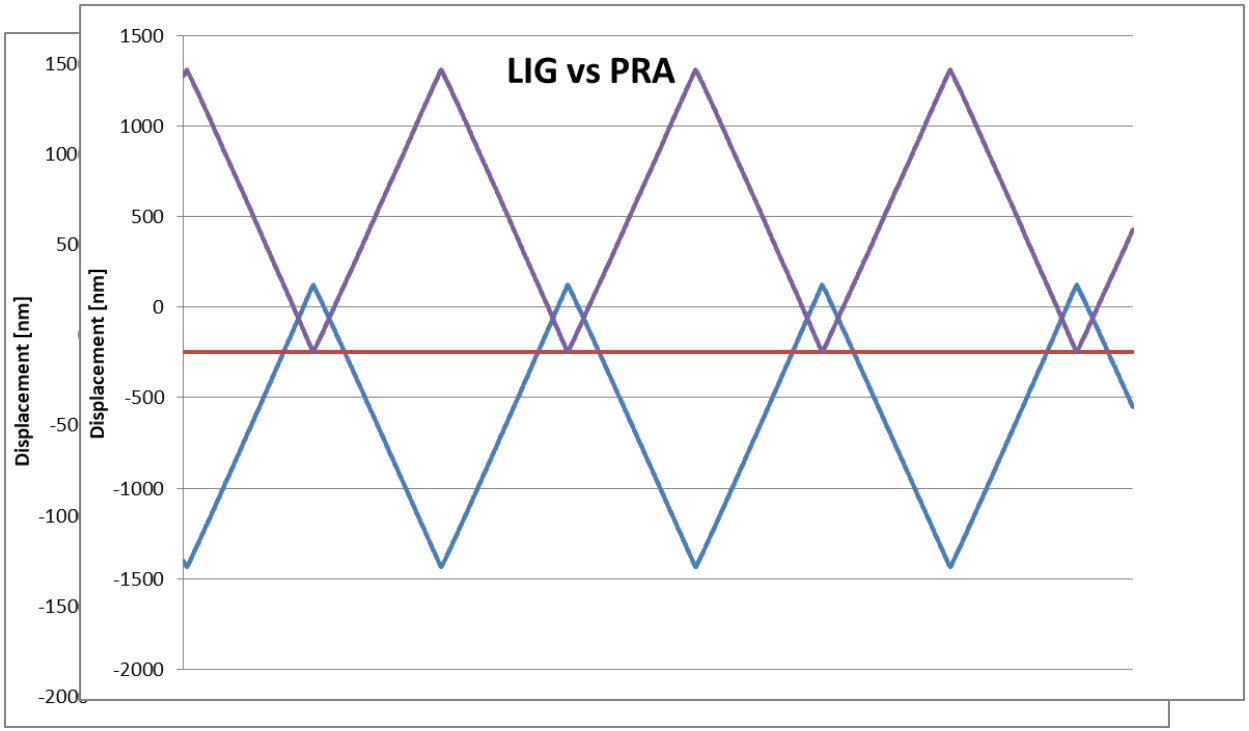
LIG vs PRA



LIG linearity test



LIG linearity test



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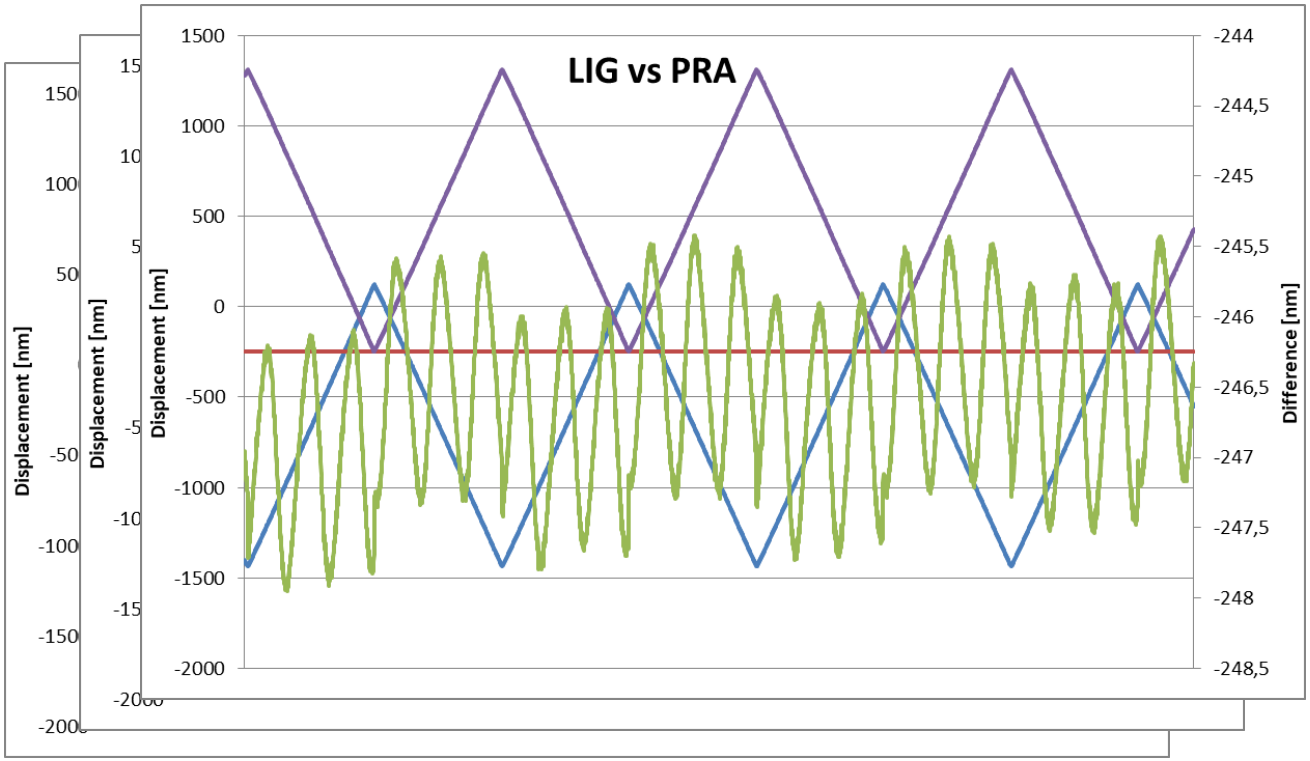
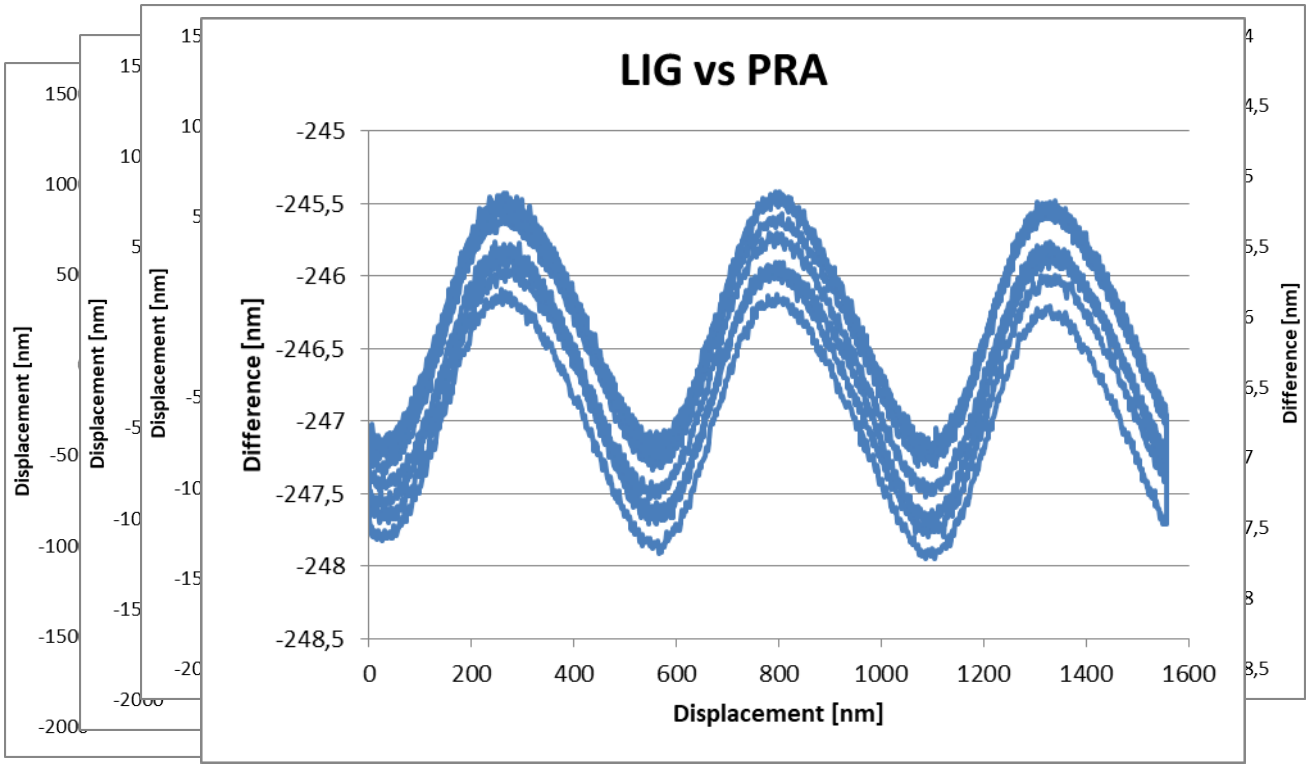
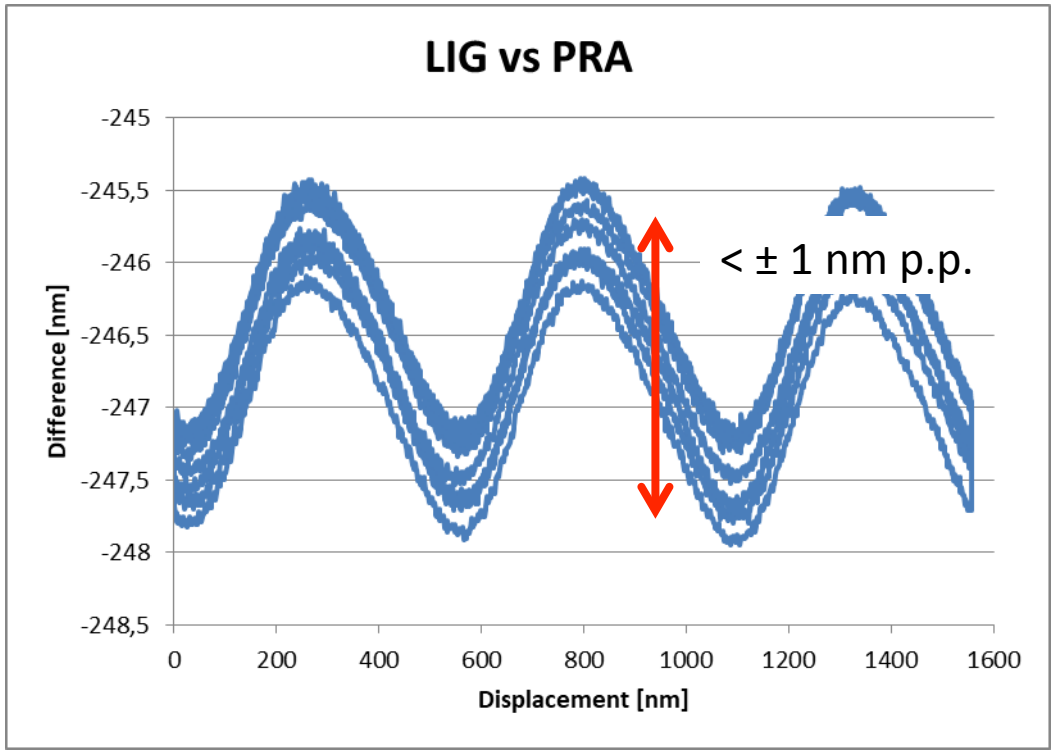


LIG linearity test



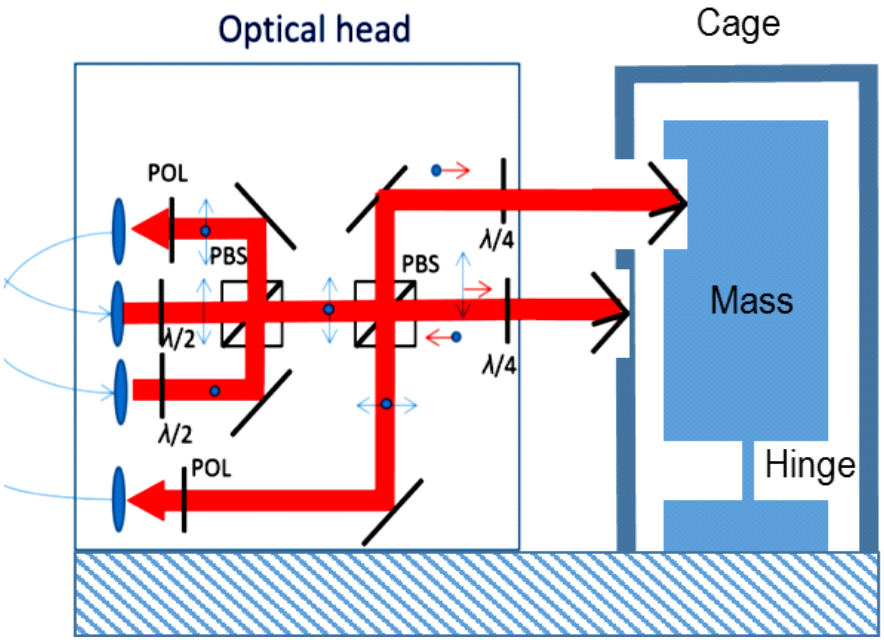
Effect of non-linearity



- 1 nm error over 1 µm wavelength → max sensitivity error of 0.1% (e.g. 10 fm over 10 pm)
- This error could be further reduced by using better polarizing optics
- Furthermore, the cyclic error is a sistematic behaviour of the interferometer that can be characterized and cancelled by post processing.

Next step

LIG-A (Laser Interferometry Gauge & Accelerometer): Integration of the interferometer in the accelerometer



Conclusions

We have realized a simple and compact interferometer based on COTS components that can be used to replace capacitive sensors in accelerometers readout

The prototype has demonstrated picometer level resolution and nanometer level non-linearities over µm wavelength.

Next step is the realization of a more compact optical head which will be embedded in an existing spring-mass accelerometer