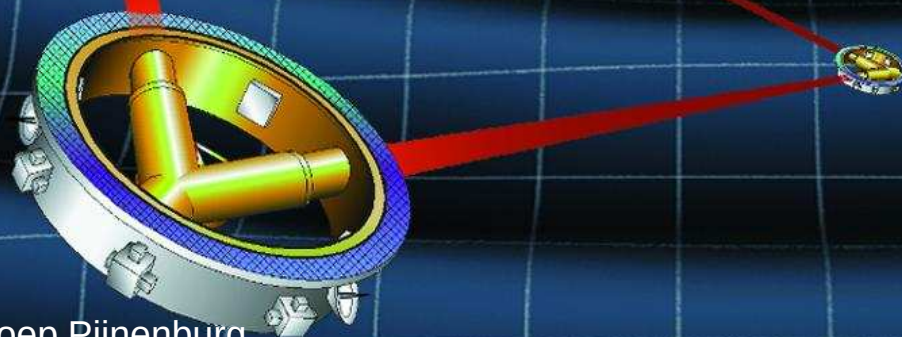


Picometer stable scan mechanism for gravitational wave detection in space

LISA - Point-Ahead Angle Mechanism

TNO | Knowledge for business



Niek Rijnveld, Joep Pijnenburg

02/12/2010

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- Driving requirements of the PAAM
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 - Performance testing
- Conclusions

Introduction: LISA mission

Goals:

- Detection of gravitational waves, experimental validation of theory of relativity by Albert Einstein;
- A new way of looking at the universe;

Currently in a technology development phase:

- Combined NASA ESA mission
- Instrumentation developed under ESA responsibility:
 - Astrium GmbH, Friedrichshafen; System level design
 - Albert Einstein Institute, Hannover; Pico meter interferometry
 - University of Glasgow: Quasi monolitical Zerodur interferometer structure
 - TNO Science and Industry, Delft: Mechanisms

Challenges:

- measure distance changes with 10 pico meter accuracy over 5 million km
- measurement band: 30 micro Hz to 1 Hz

Introduction: LISA mission

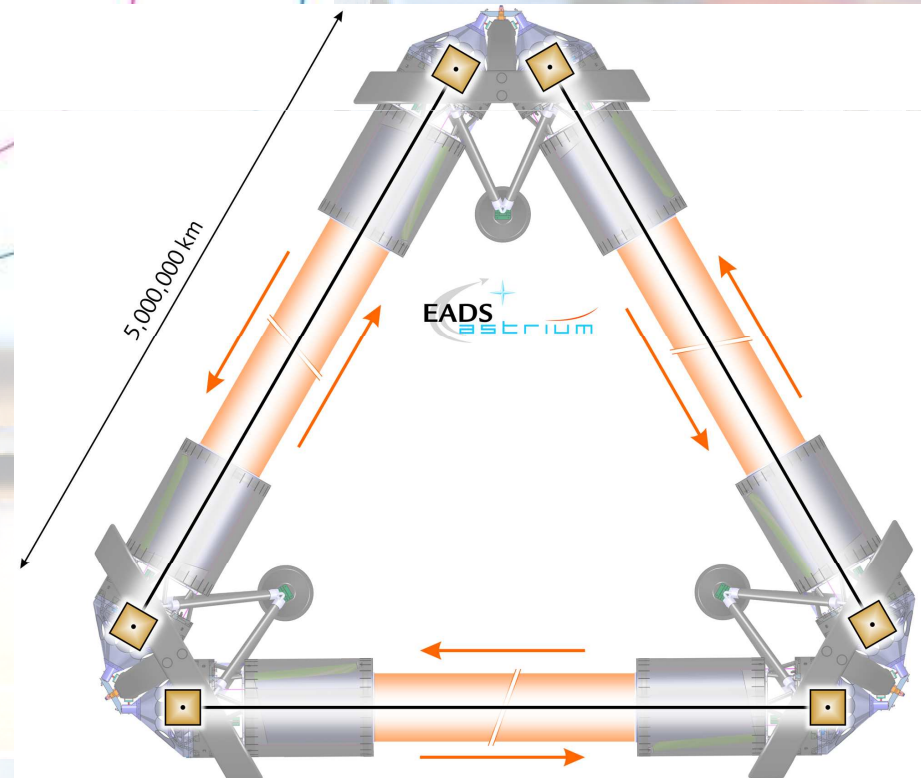
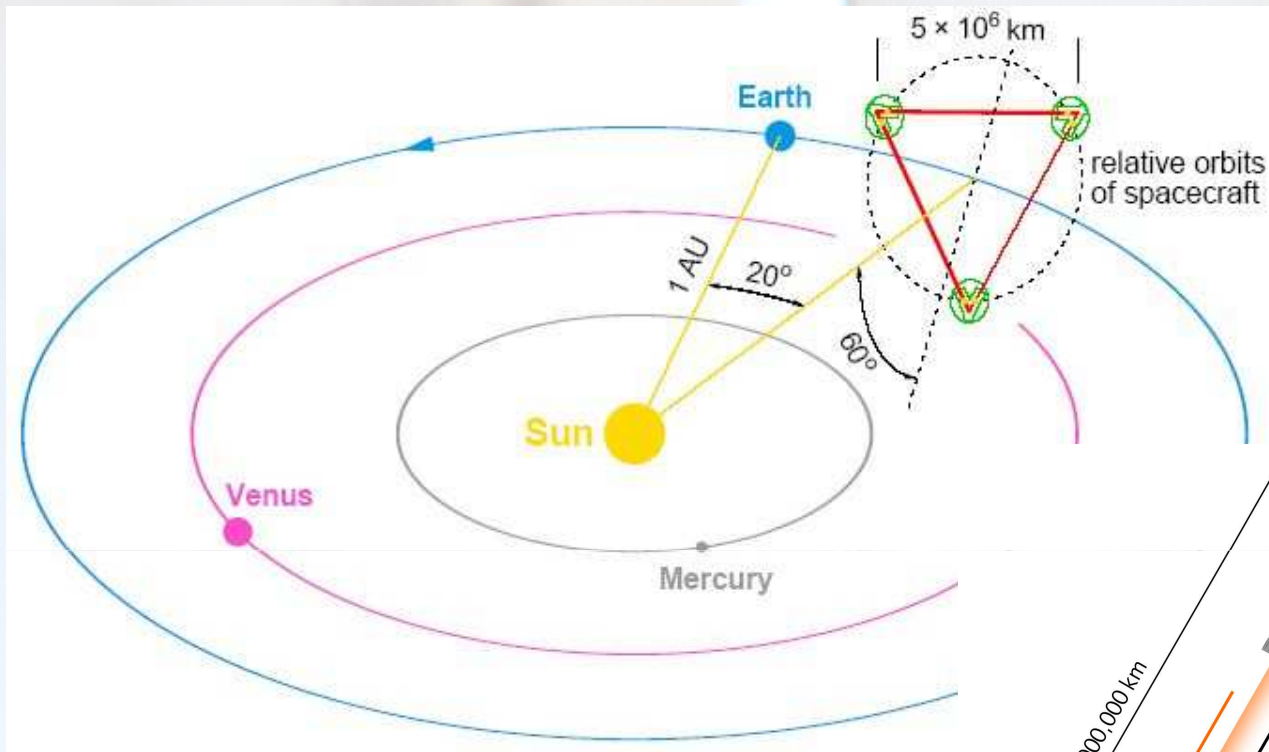


Image courtesy:



Precisiebeurs 2010

Introduction: LISA mission

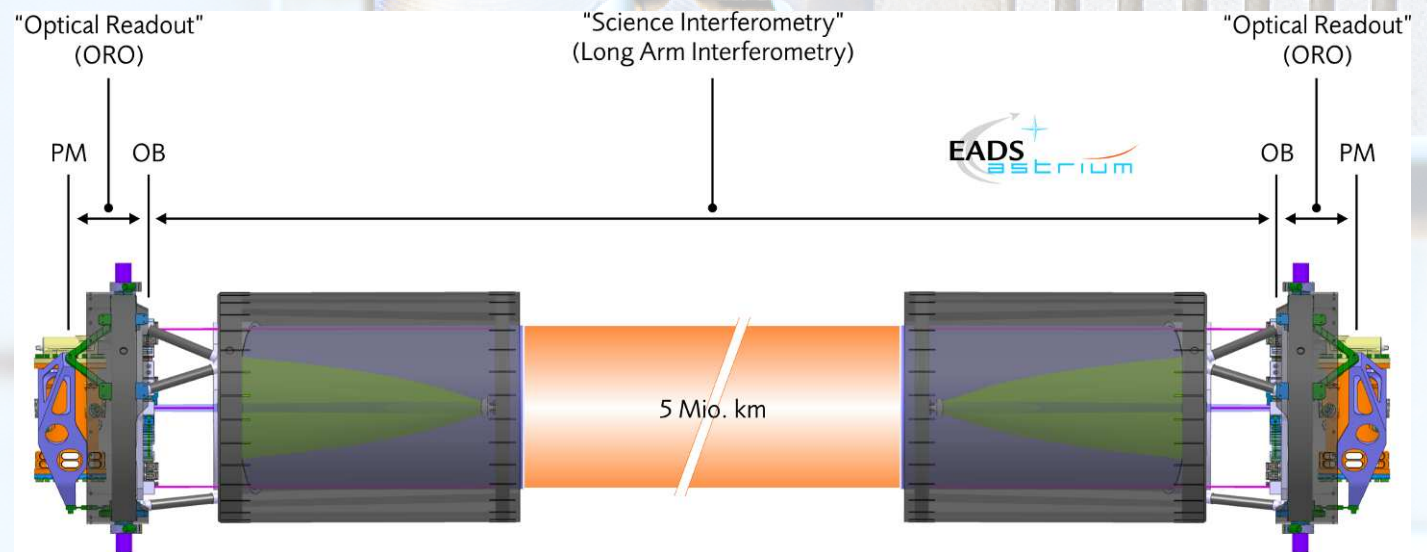
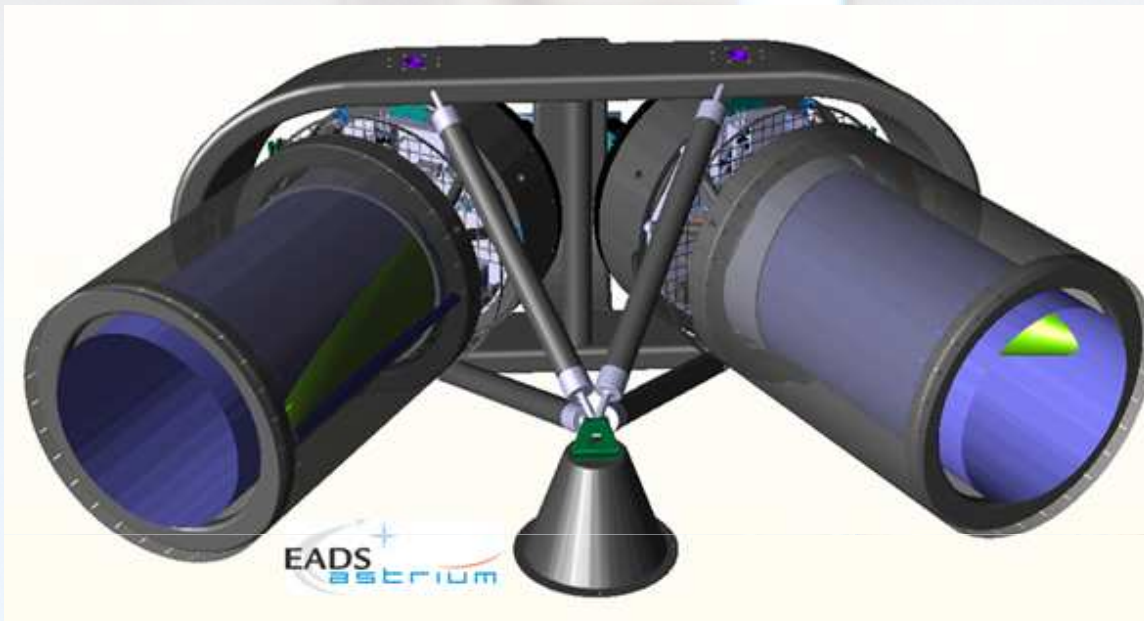


Image courtesy:



Precisiebeurs 2010

Introduction: LISA mission

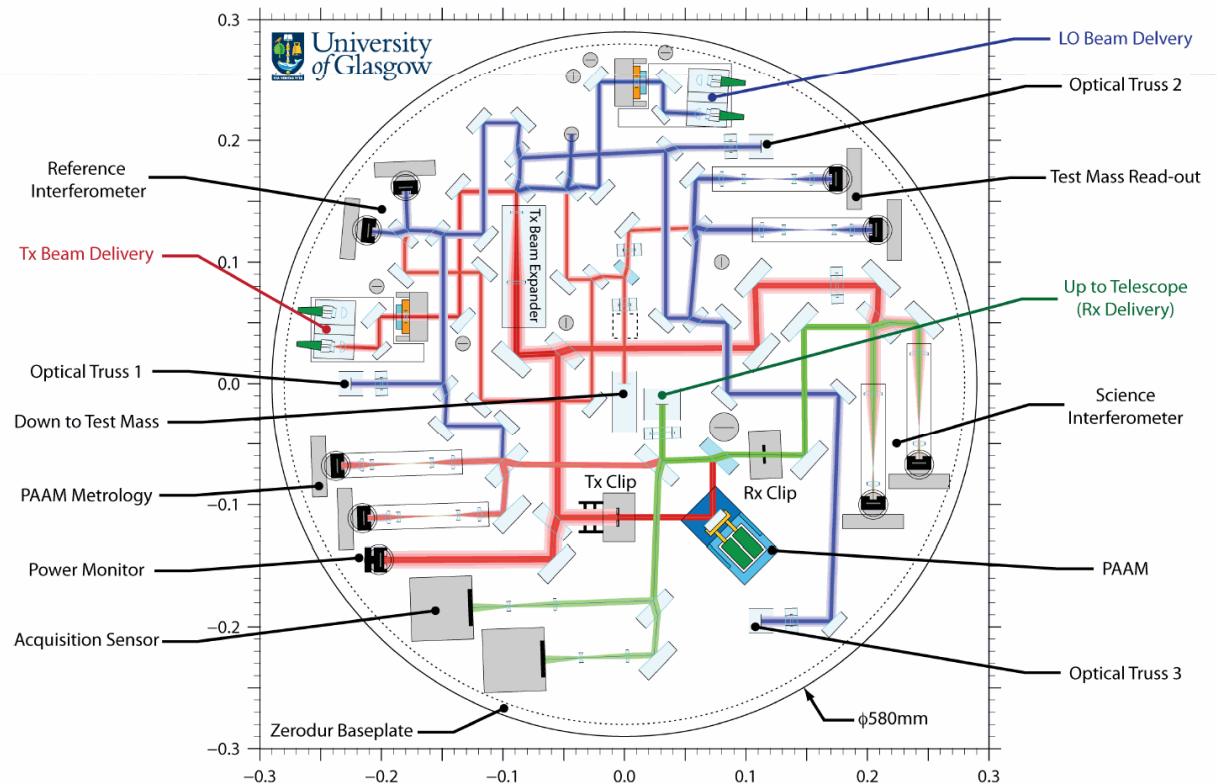
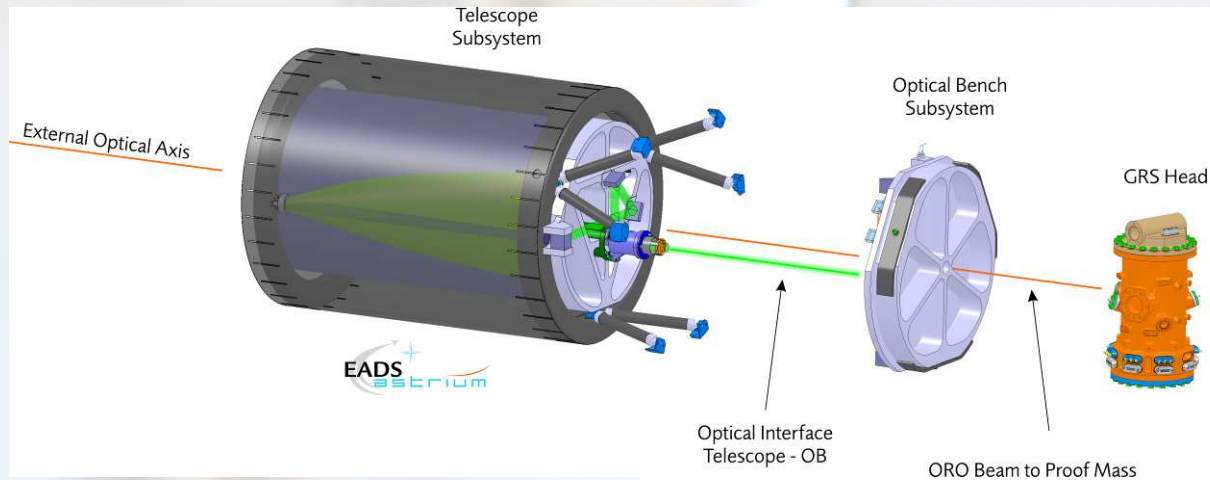


Image courtesy:



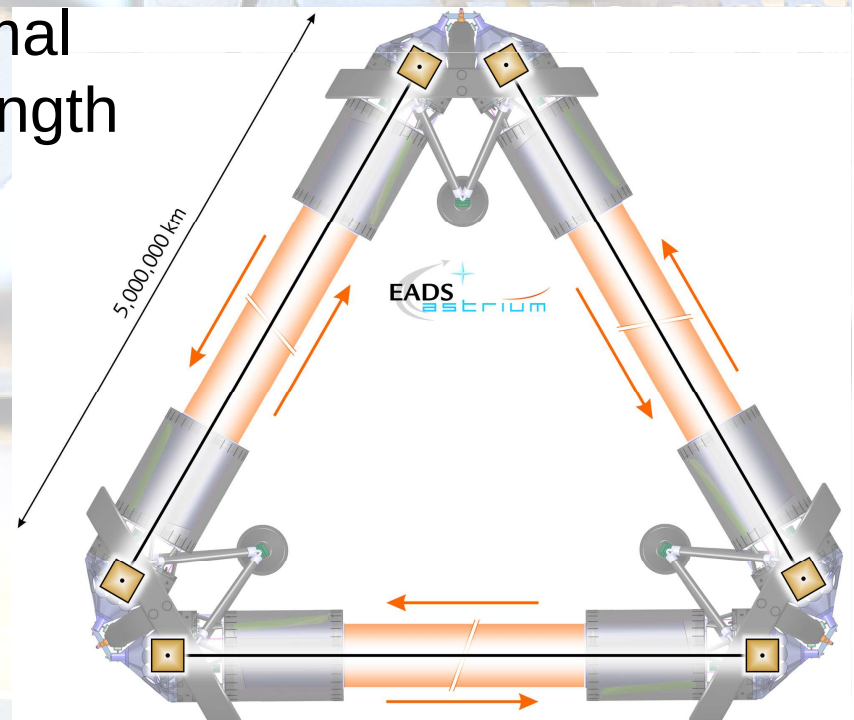
Precisiebeurs 2010

TNO contribution in LISA mission

- Point Ahead Angle Mechanism;
 - Piezo actuated tilt mechanism
- Fiber Switching Unit
 - Piezo Inertia actuated rotation mechanism
- Refocusing Mechanism
 - Piezo Inertia actuated translational mechanism
- In Field Pointing Mechanism
 - Piezo stepping tilt mechanism
- Characterization of Telescope stability
 - Length measurements with nanometer accuracies at -90 degrees Celsius

Point-Ahead Angle Mechanism

- Due to the time delay of the travelling light between the space crafts, the laser beam angle has to be corrected
- The Point-Ahead Angle Mechanism will perform this task, with minimal noise contribution to the path length of the laser beam



Study logic

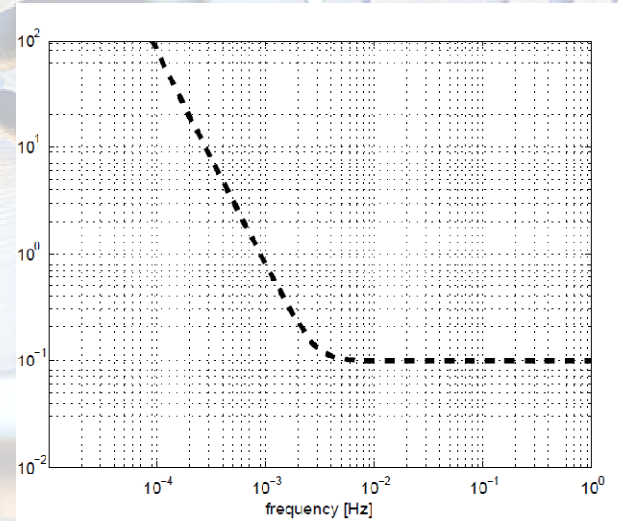
- Challenge:
 - Technology demonstration for nanoradian and picometer stability in extremely low frequencies. The Lisa Measurement Band (LMB): from 0.03 mHz to 1 Hz.
- Study logic:
 - Design concepts trade-off
 - Preliminary concept design
 - Component testing
 - Design finalization and realization
 - Elegant Bread-Board testing

Driving requirements

Performance requirements:

- OPD and angular jitter noise shape between 0.1 mHz (goal: 0.03 mHz) and 1 Hz:

$$n(f) = \sqrt{1 + \left(\frac{2.8 \text{ mHz}}{f} \right)^4}$$



- OPD specification: $1.4 \text{ pm} / \sqrt{\text{Hz}} \cdot n(f)$
- Angular jitter specification: $16 \text{ nrad} / \sqrt{\text{Hz}} \cdot n(f)$

Driving requirements

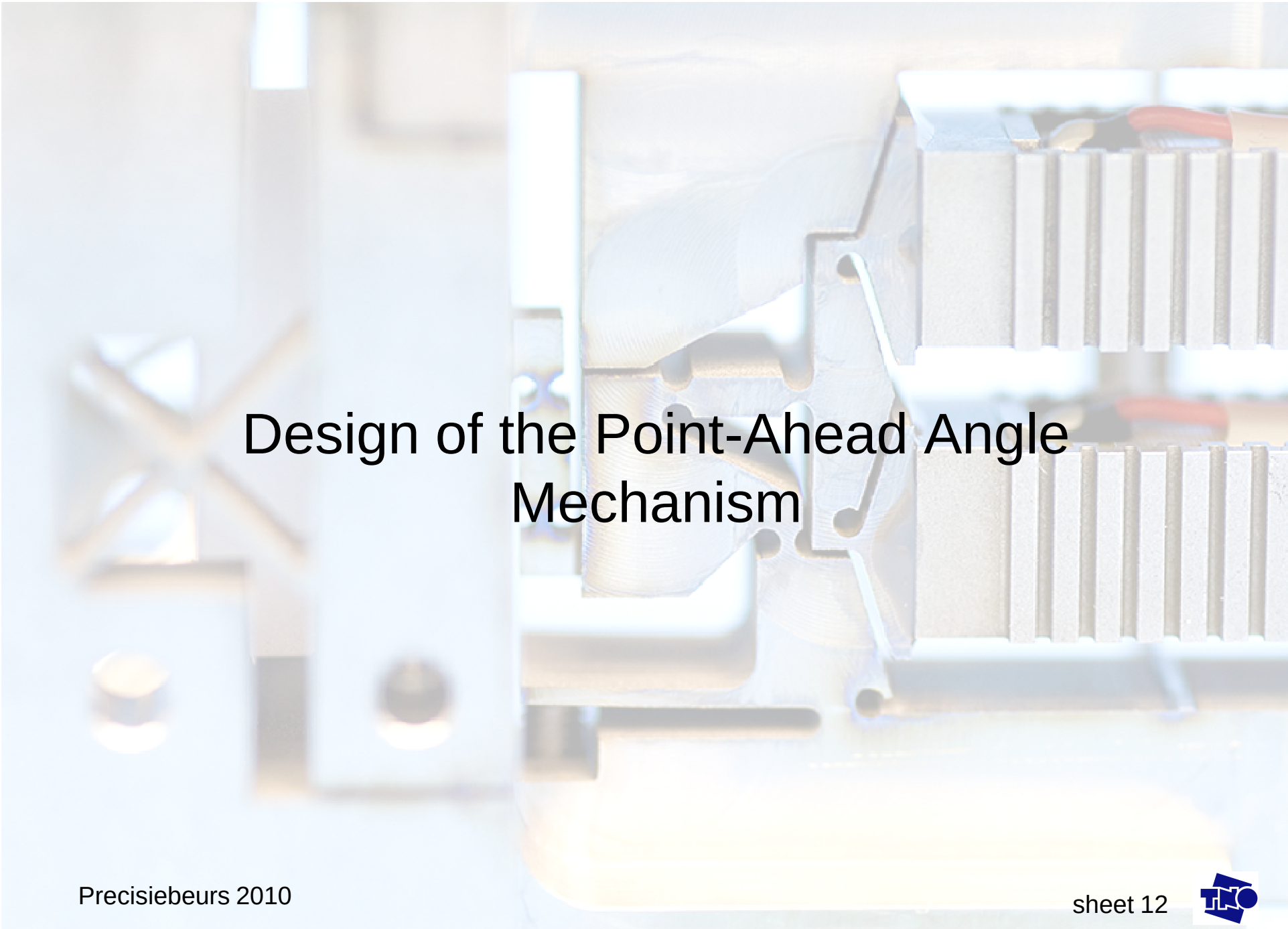
Functional requirements:

Steer incoming laser beam with extremely high stability

- Optical range: $\pm 824 \mu\text{rad}$

Environmental requirements:

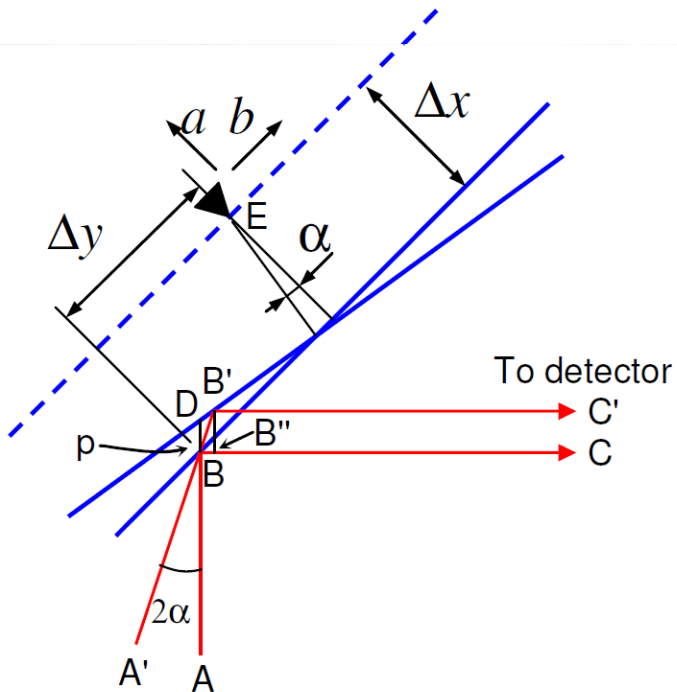
- No magnetic materials allowed
- Random Vibrations loads of 25 g RMS
- Thermal cycling -10 to 80 degrees Celsius
- Minimal contamination allowed



Design of the Point-Ahead Angle Mechanism

Optical design

- Concept: rotating mirror to steer beam
 - Low transmission losses
 - Low complexity
 - Minimal contribution to OPD



Main contributors OPD:

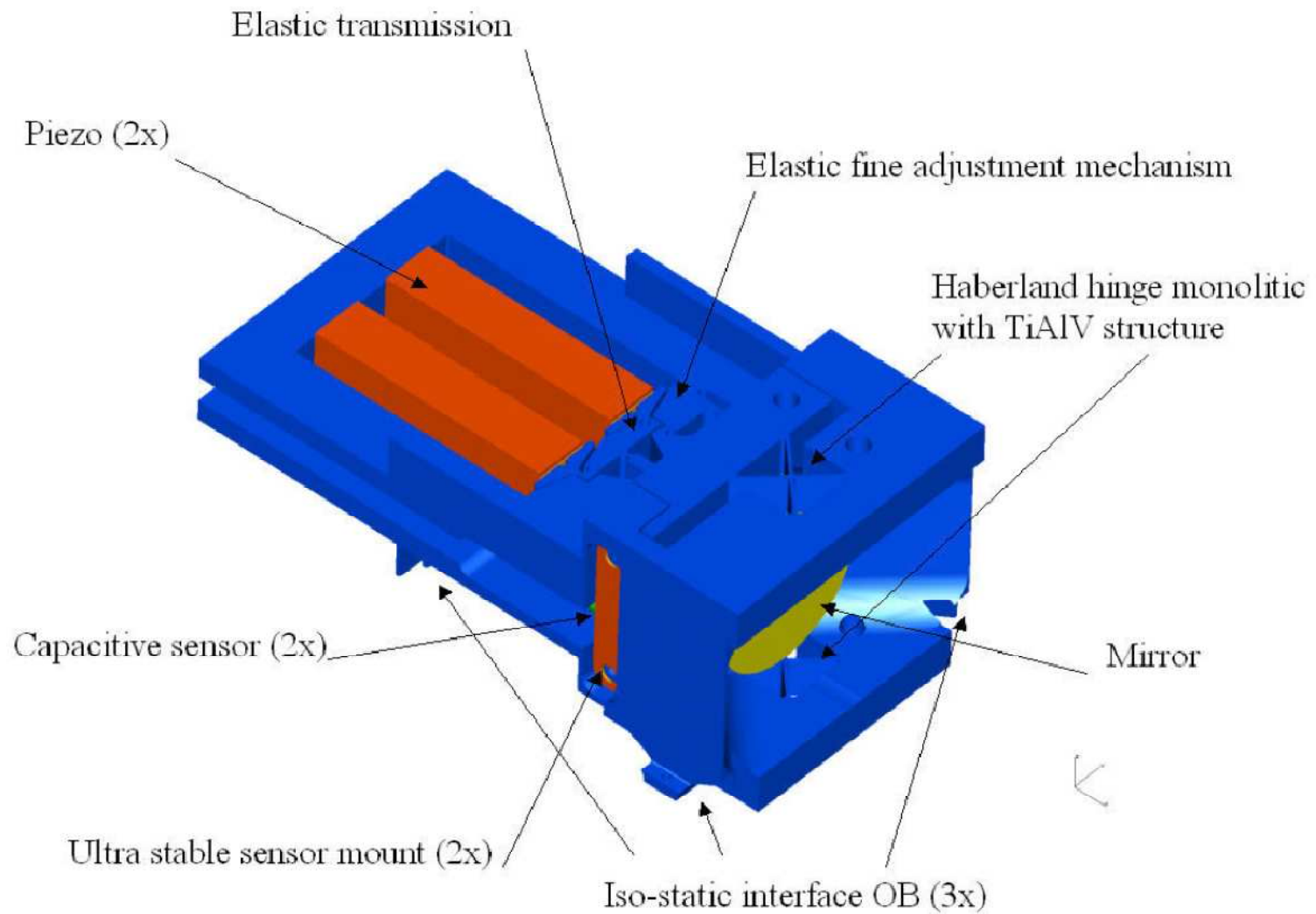
- Angular jitter $\Delta\alpha$ through misalignment Δy
- Piston jitter $\delta\Delta x$
- Rotation axis jitter δa during motion



Expected major noise contributors and what has done to minimize them.

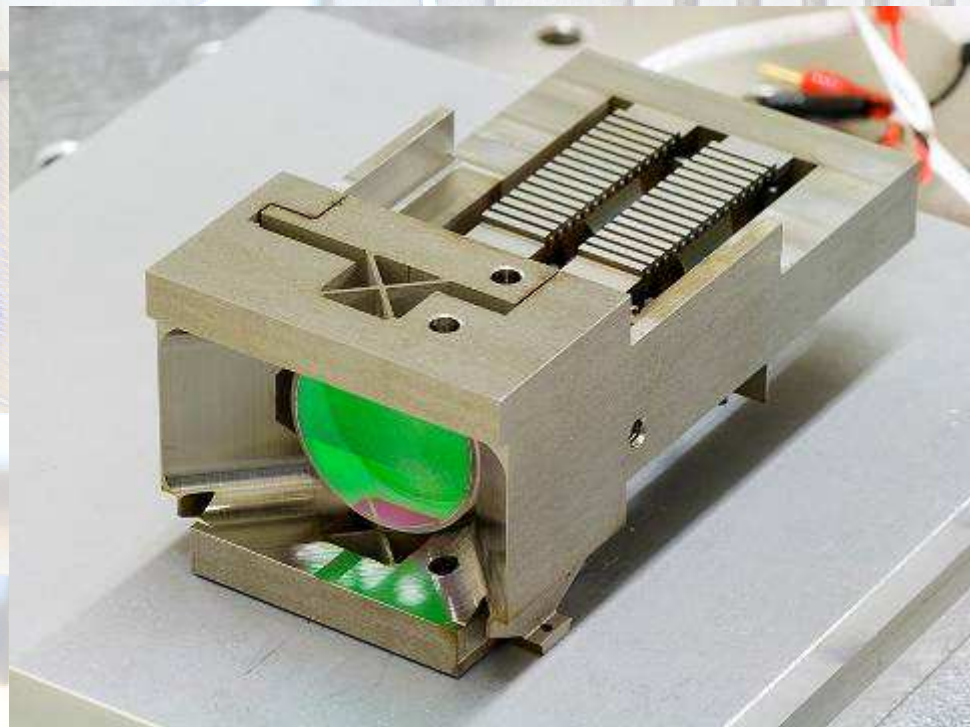
- Structural dynamical
 - Not critical due to:
 - measurement band 0.03 mHz to 1 Hz
 - extreme low vibration levels on space crafts
- Structural
 - Minimize (actuation) forces in OPD direction (and LMB)
 - Keep mechanism as symmetric as possible.
- Thermo elastic
 - Athermal construction.
 - Minimize heat dissipation.
 - Keep mechanism as symmetric as possible.
- Dimensional
 - Material with high dimensional stability.
 - Minimize number of mechanical interfaces.
- Bearing
 - Avoid friction and wear (performance and contamination)
- Control loop
 - Control performance in LISA measurement band will be dominated by sensor (electronics) noise.

Components in the PAAM



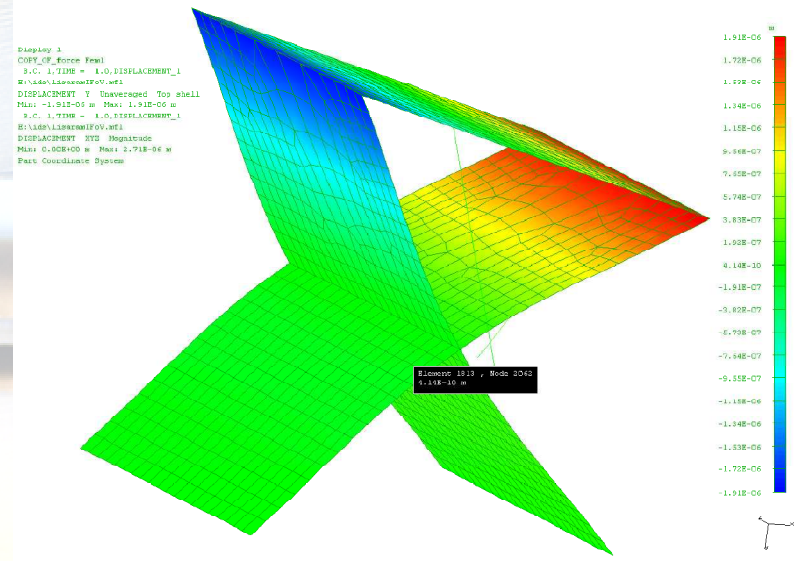
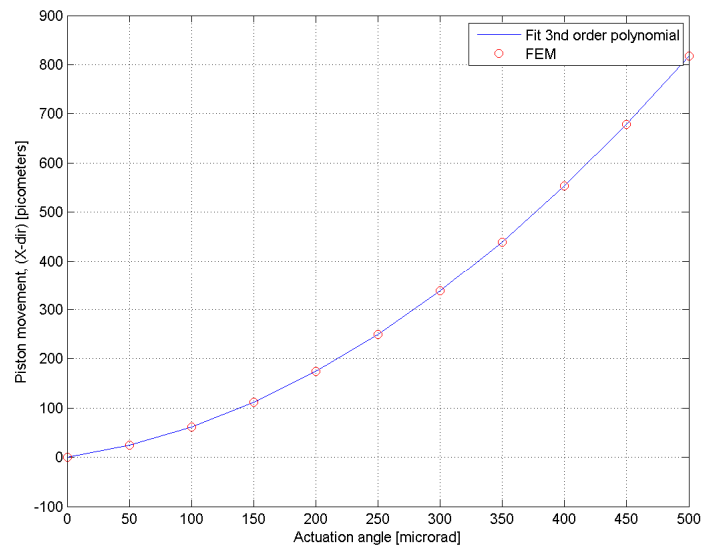
Mechanical design

- Rotational bearing: Haberland hinge
 - Non-magnetic
 - No contamination
 - Stable
 - No friction
- Monolithical structure
- Material: $\text{Ti}_6\text{Al}_4\text{V}$
 - High yield stress
 - High dimensional stability



Mechanical design

- Finite element analysis of worst case rotation axis jitter in Haberland hinge, including production tolerances ($\pm 10 \mu\text{m}$)
- Maximum piston motion at extreme mirror angle: 720 μm
- Piston sensitivity: $< 2.1 \text{ fm} / \text{nrad} \rightarrow$ within budget

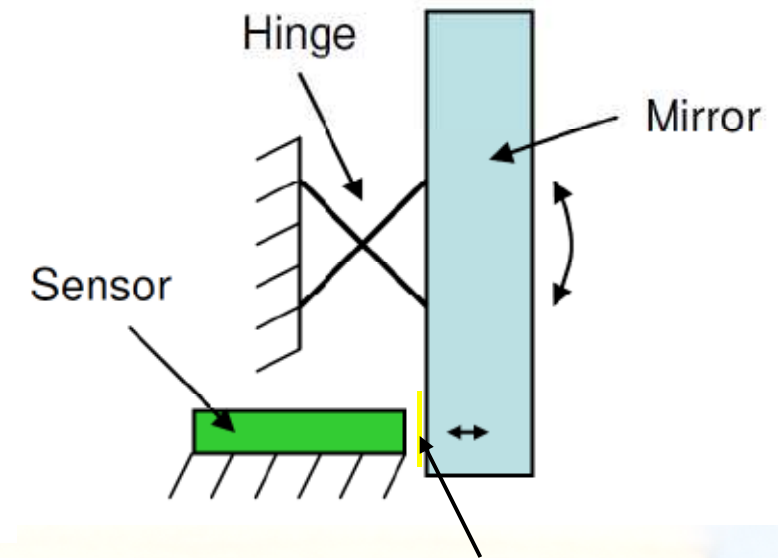
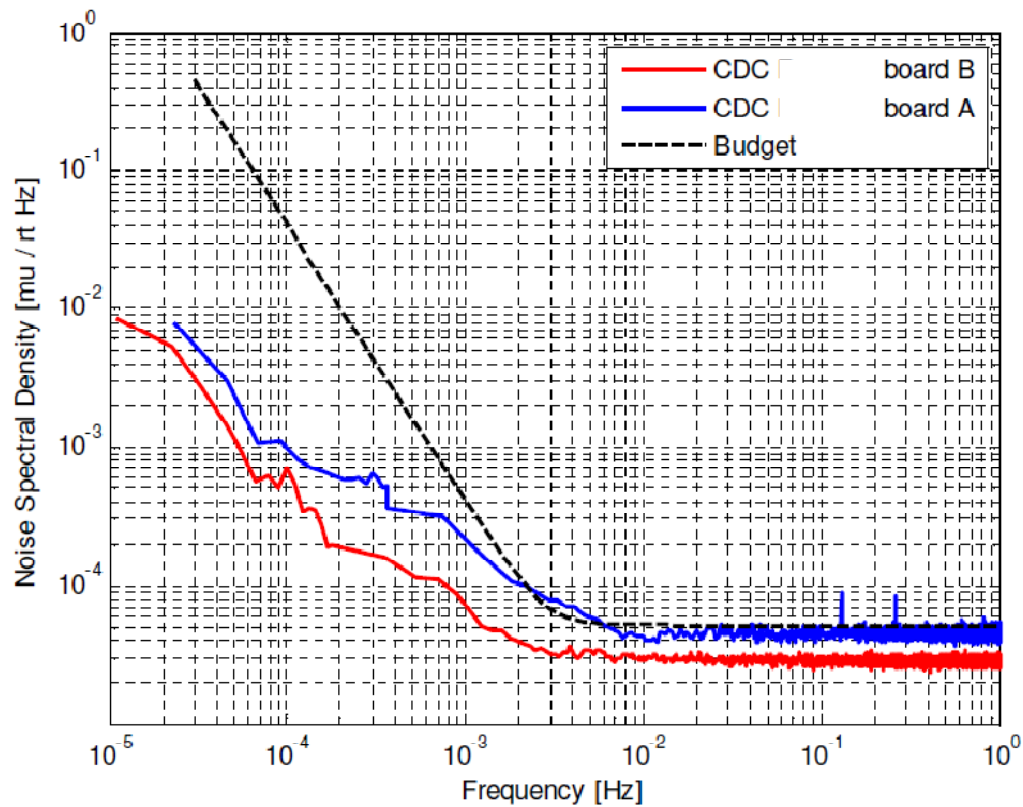


Control design

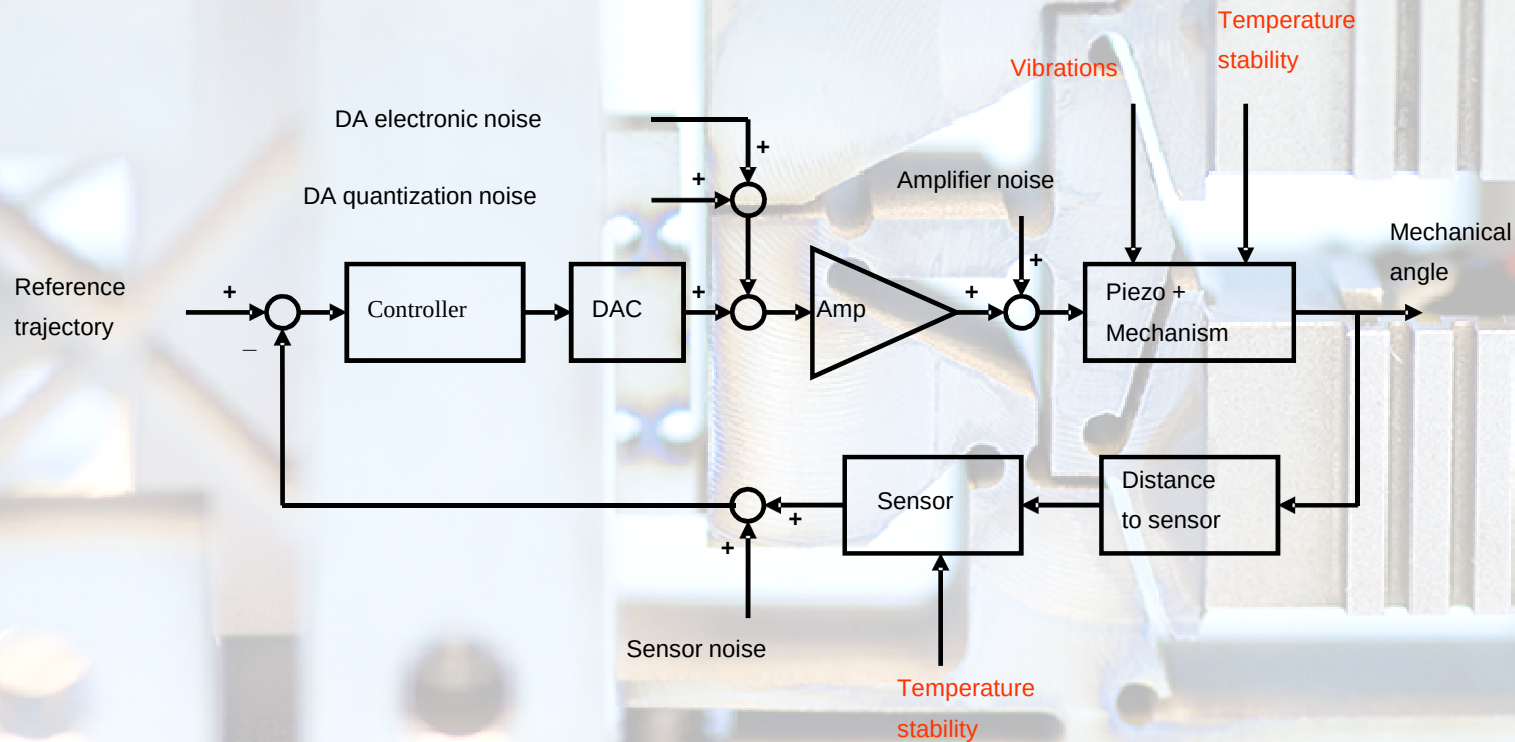
- Piezo: translates voltage into displacement
- Closed loop system to compensate for piezo discharge and hysteresis
- Controller: simple integrator with additional roll off
- Band width: 10 Hz
- Accurate sensor required!

Electronic design

Sensor:

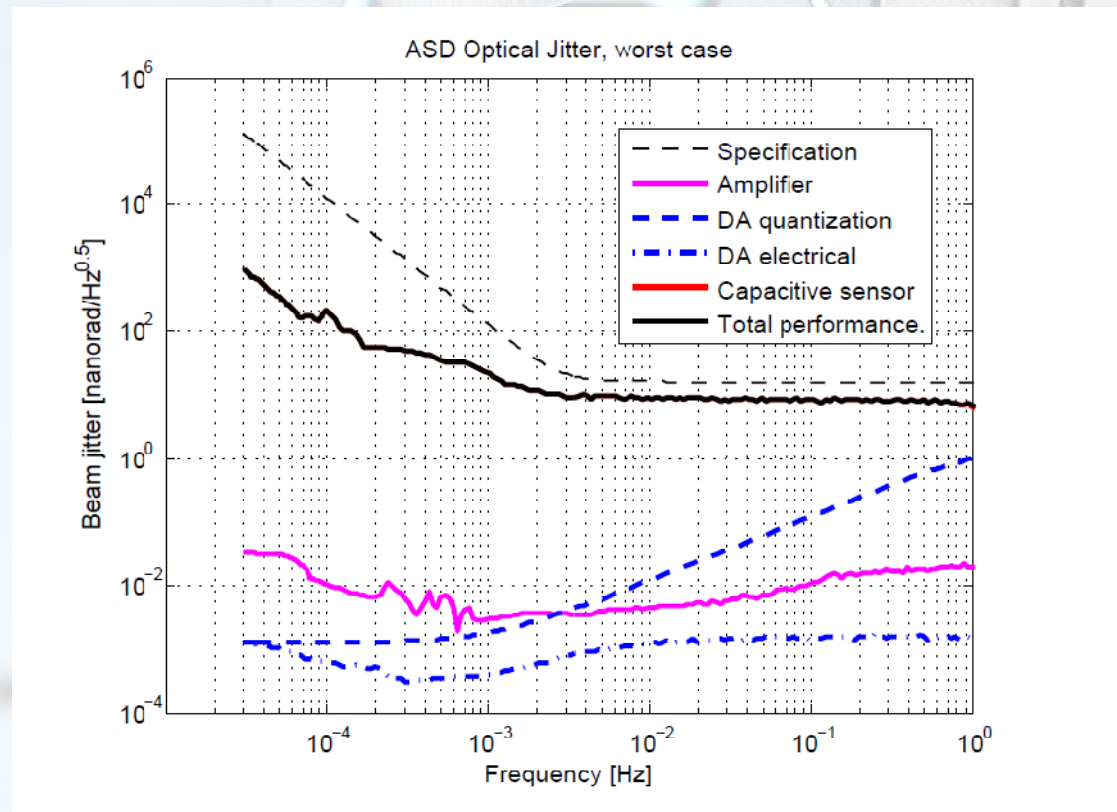


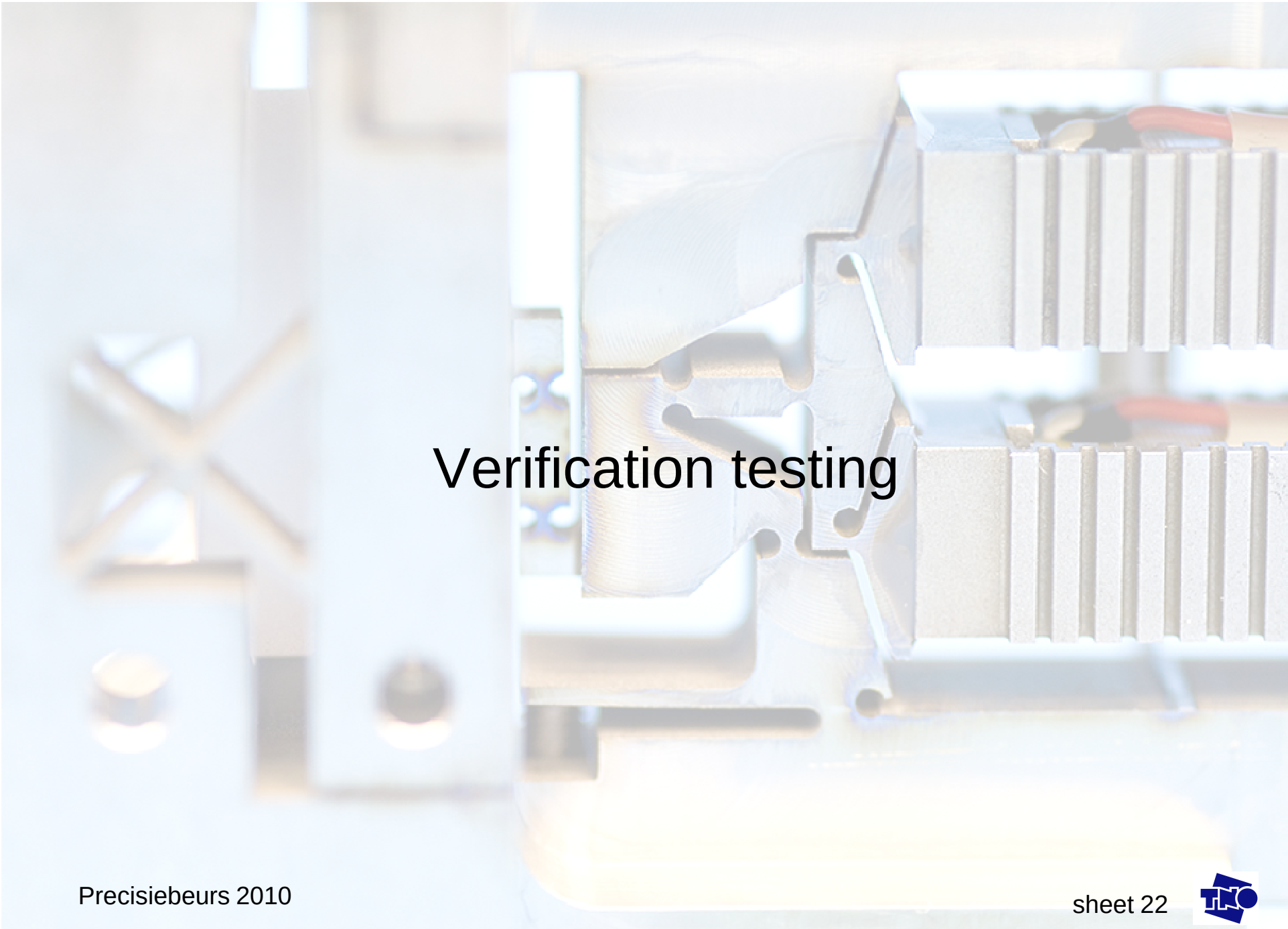
Performance prediction model of control



Performance prediction

- Capacitive sensor noise dominant in performance prediction



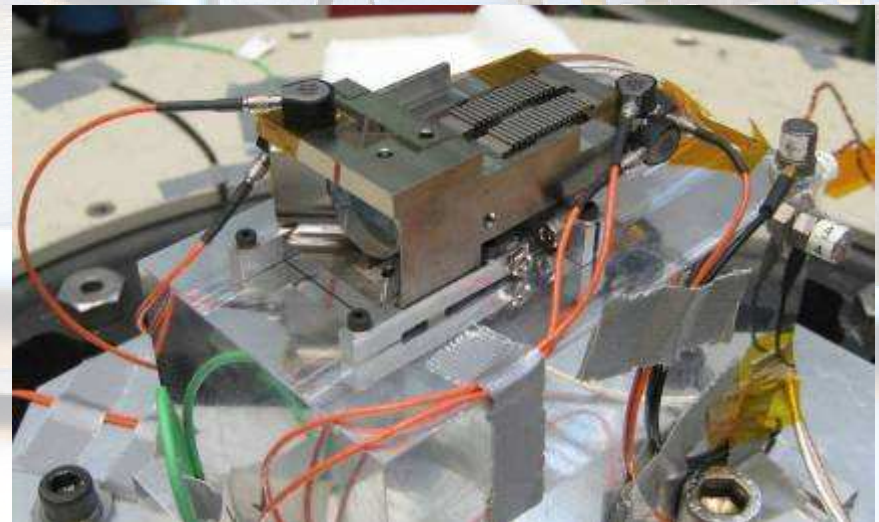
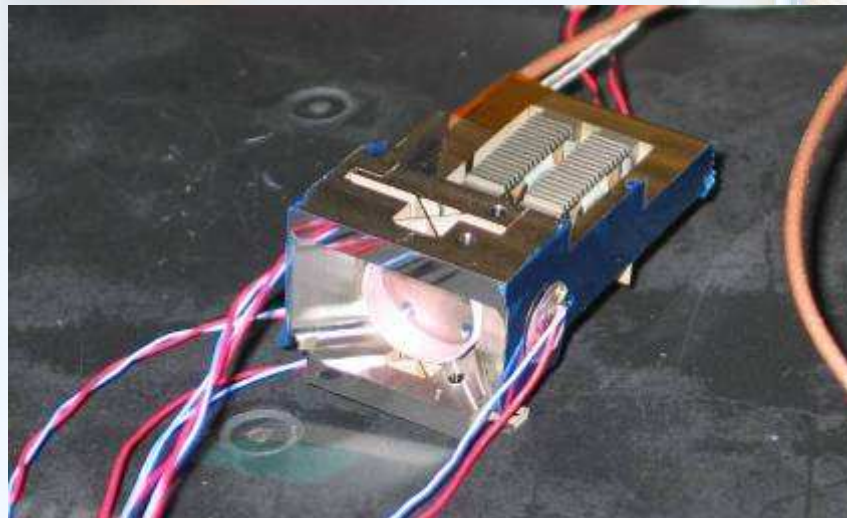


Verification testing

Environmental testing

Thermal cycling between
+ 80 °C and - 10 °C

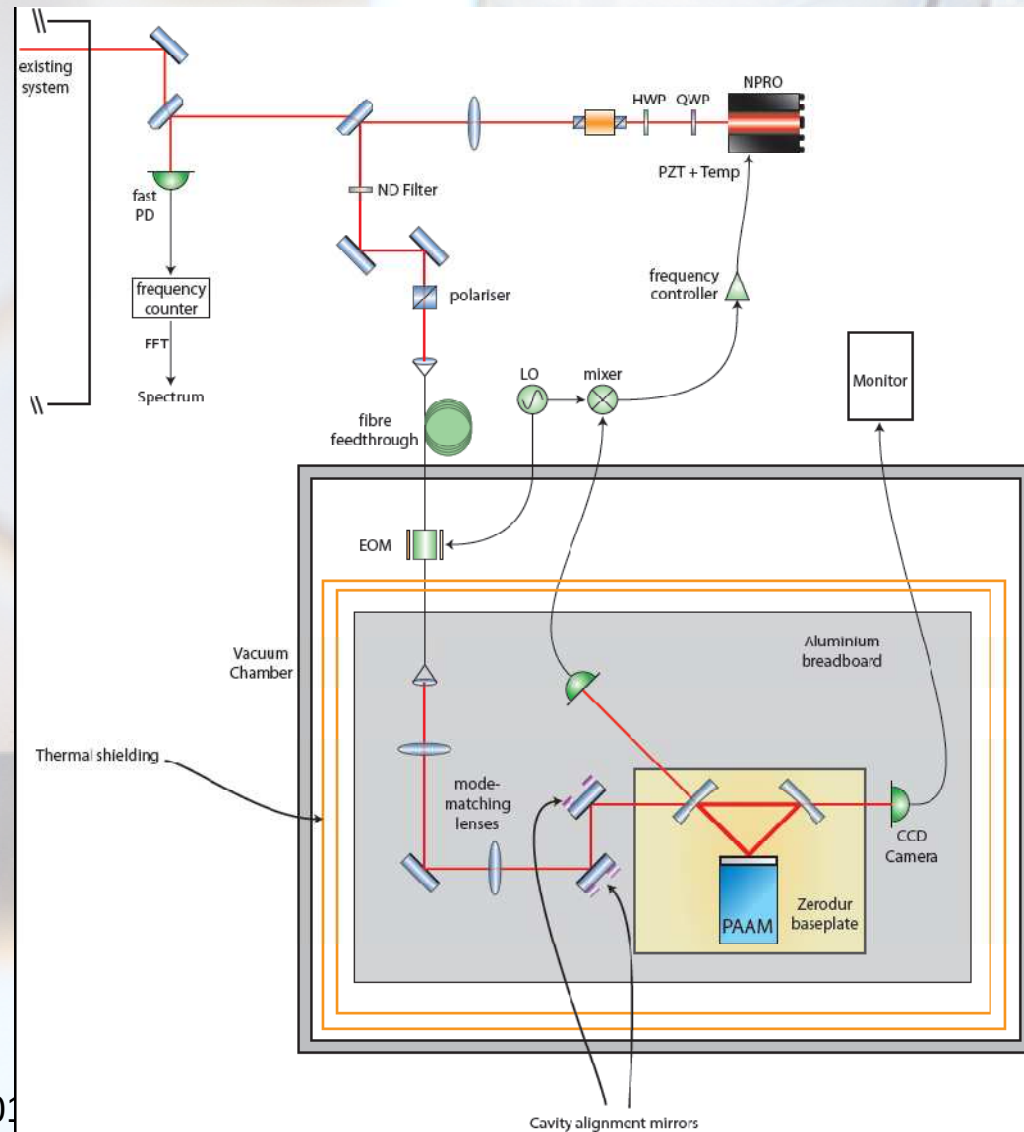
25 g RMS random vibration
testing



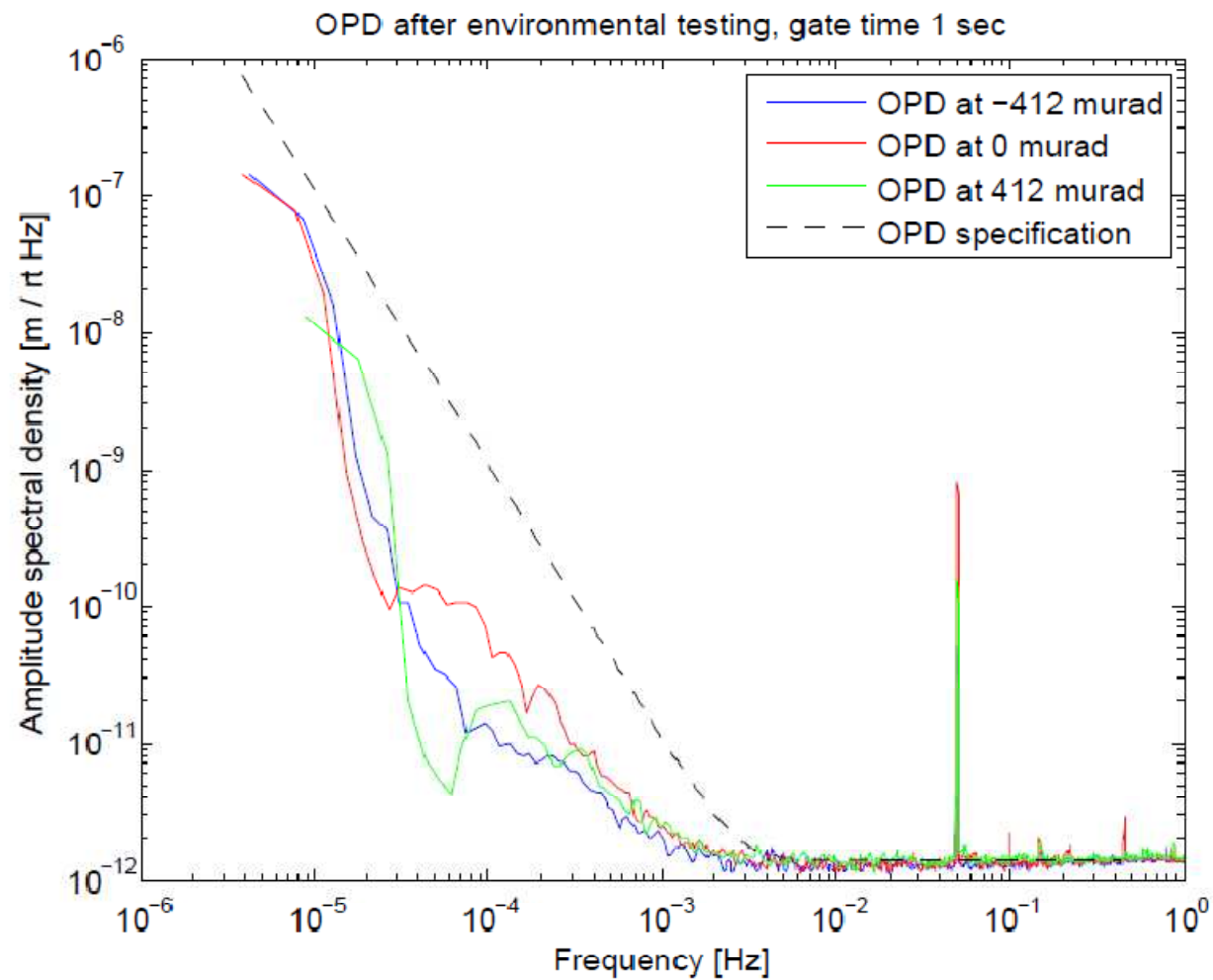
Performance testing

- Test set-up Albert Einstein Institute to measure picometers:
 - Vacuum chamber pumped down to 10^{-4} bar
 - Temperature stability: $14\mu K / \sqrt{Hz} \cdot n(f)$
 - Interferometer with triangular resonance cavity
 - Cavity controlled by EOM
 - Cavity resonance beatnote measured with frequency counter

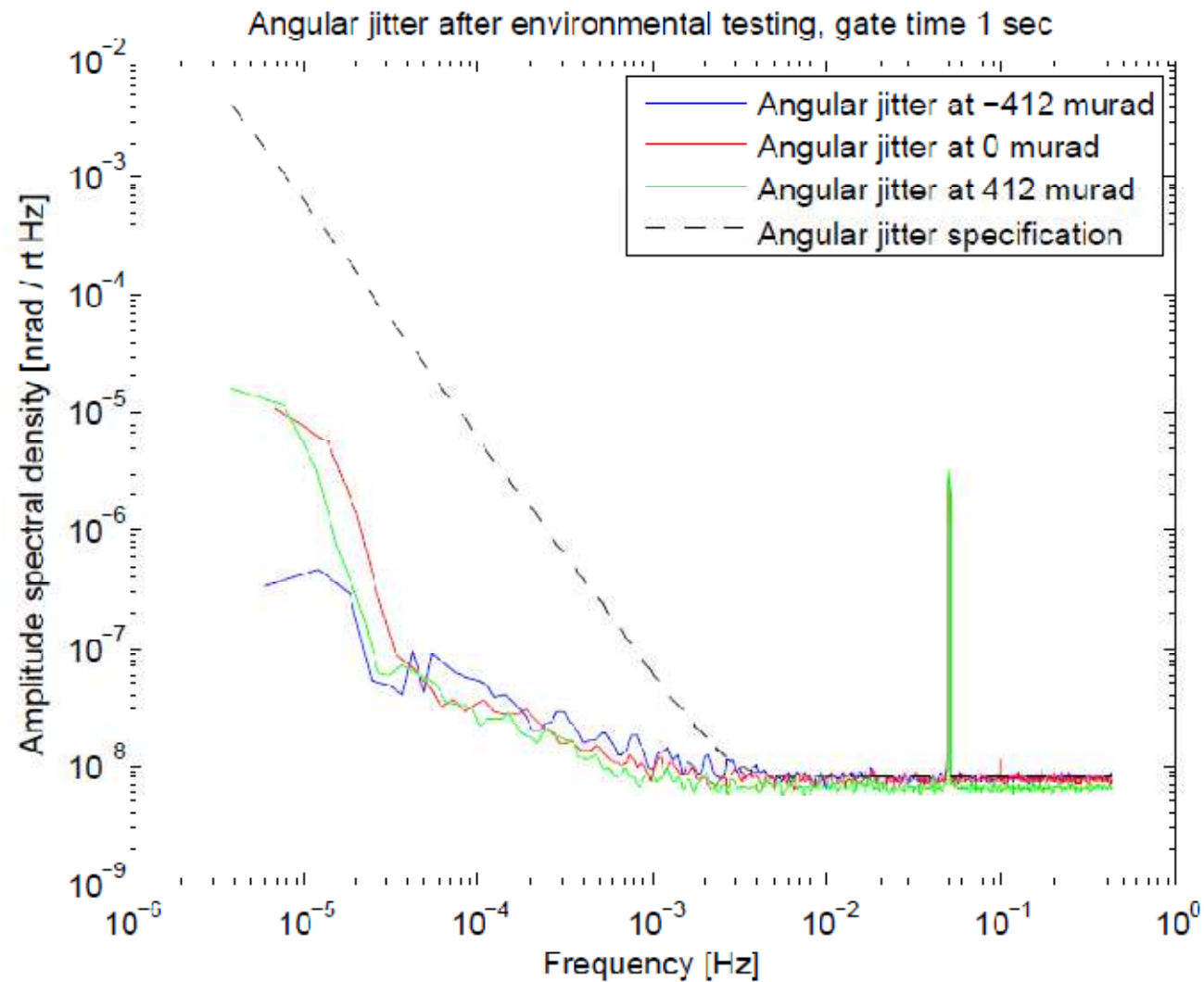
Performance testing



Performance testing after ET

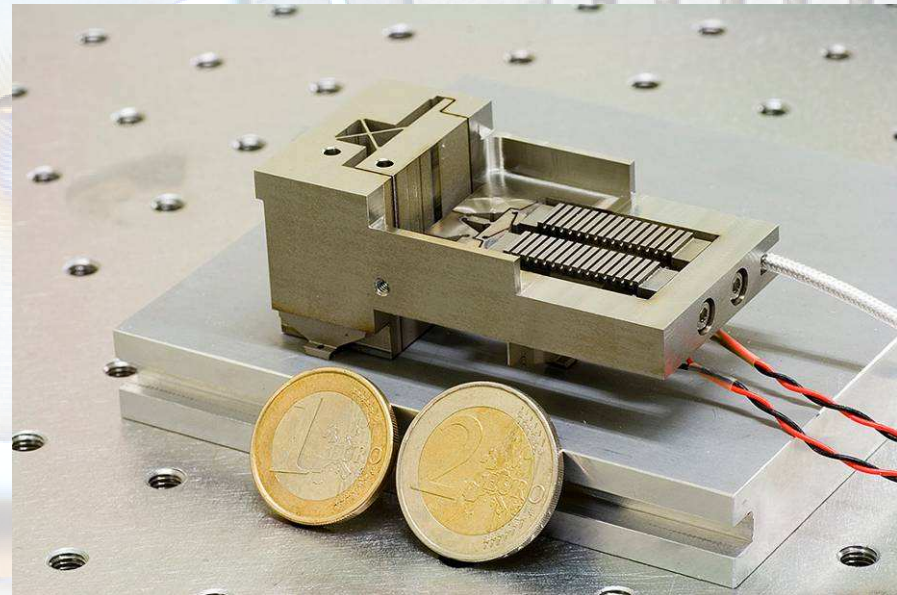


Performance testing after ET



Conclusions

- Beam steering with picometer and nanoradian stability!
- Critical in performance:
 - Sensor and electronics noise
- Non-critical in performance by design:
 - Rotation axis jitter
 - Dimensional and thermal stability



Next steps

- Include in LISA Optical Bench test set-up
- Engineering Model?
- For out-of-plane angle:
 - Develop large range system
 - ± 5 degrees
 - Piezostepper

Acknowledgements

- TNO has been able to demonstrate the performance thanks to the work, expertise and spirit of the Albert Einstein Institute and also thanks to the cooperation with the Technical University of Delft

Questions?

**Please visit our
booth**

Niek Rijnveld

