An optical readout system for the drag free control of LISA

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We present a study for an optical readout system for the LISA GRS

The goal is not the replacement of the capacitive sensor with an optical one but the integration of the optical readout in the present design of the GRS (with minimum modification)

the motivations are:

• risk reduction: in order to have a back-up readout in case the capacitive one fails after the launch

• redundancy: an independent readout provides extra information on couplings etc.

• sensitivity: an optical readout is potentially more sensitive for some DOF.

In order to be implemented on LISA, the system should fulfil some condition

• enough sensitivity => we assume as an acceptable levels:

$$\delta x \leq 10^{-9}\ \mathrm{m/Hz^{1/2}}$$

$$\delta\theta \leq 5\cdot 10^{-8}\ \mathrm{rad/Hz^{1/2}}$$

• low back action => we assume:

$$\delta F \leq 6\cdot 10^{-16}\ \mathrm{N/Hz^{1/2}}$$

• The system should require very small modifications of the hardware already tested on flight with LTP (it should better be tested on LTP but there is very little time left).

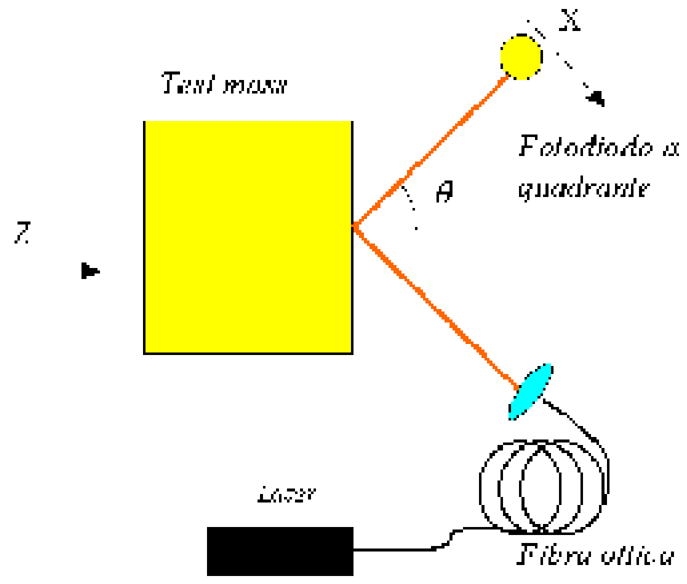
Optical lever sensor

With these requirements in mind we have selected as a simple solution the usage of optical levers:

A laser beam is sent trough a SM optical fibre to the test mass and the position of the reflected beam is measured with a position sensor (Quadrant photodiode of PSD)

the sensitivity depends on input power and measurement range (beam size for QPD or detector size for PSD)

with a suitable combination of three beams and sensors we can recover the six DOF of the test mass



some relevant noise sources

shot noise

$$\tilde{x}_{sm} \approx 2.8 \cdot 10^{-11} \left(\frac{633\text{nm}}{\lambda}\right)^{1/2} \left(\frac{1\text{mW}}{P_0}\right)^{1/2} \left(\frac{0.78}{\eta}\right)^{1/2} \left(\frac{L}{1\text{mm}}\right) \left[\text{m}/\sqrt{\text{Hz}}\right]$$

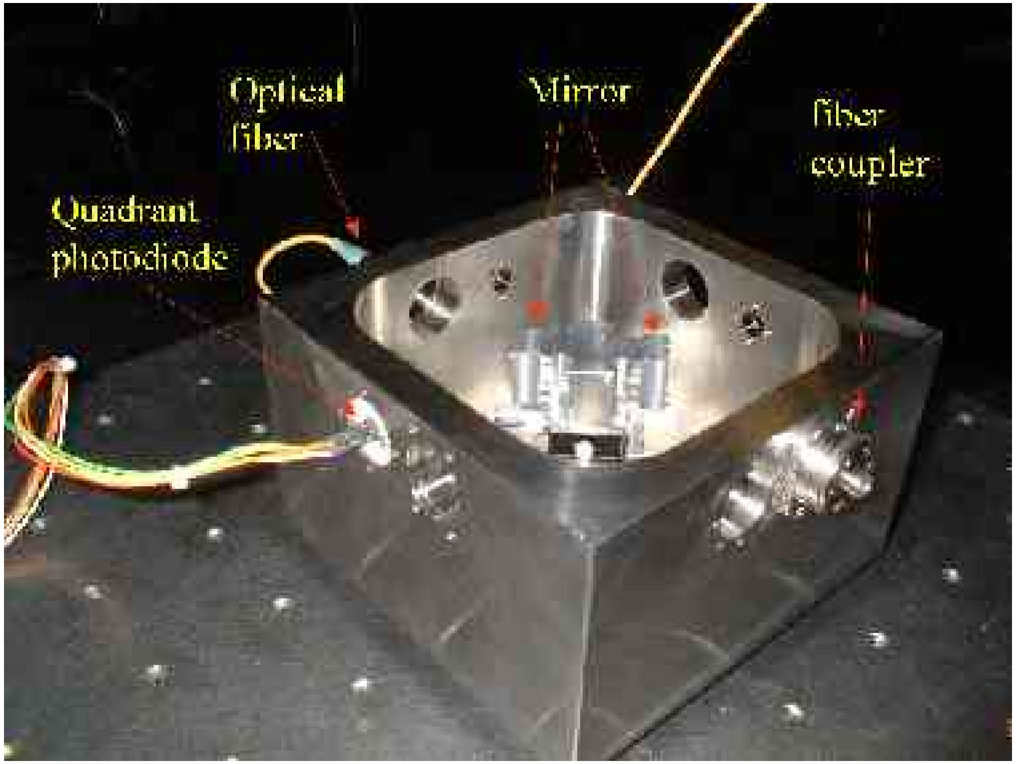
amplifier current noise

$$\tilde{x}_I = \frac{L \cdot \tilde{I}_n(f)}{\alpha \cdot P_0} \approx 4.2 \cdot 10^{-10} \left(\frac{\tilde{I}_n(1\text{mHz})}{1.7 \cdot 10^{-10}}\right) \left(\frac{1\text{mW}}{P_0}\right) \left(\frac{1\text{mHz}}{f}\right)^{1/2} \left(\frac{L}{1\text{mm}}\right) \left[\text{m}/\sqrt{\text{Hz}}\right]$$

power fluctuations

$$\tilde{F} = \frac{2 \cdot \tilde{P}}{c} \leq 6 \cdot 10^{-16} \left[\text{N}/\sqrt{\text{Hz}}\right] \Rightarrow \tilde{P} \leq 10^{-7} \left[\text{W}/\sqrt{\text{Hz}}\right]$$

Some bench-top measurements



the bench is machined from a single block of stainless-steel and has interfaces for fiber couplers and sensors.

the "test mass" ha some mirror attached and can be moved for calibration

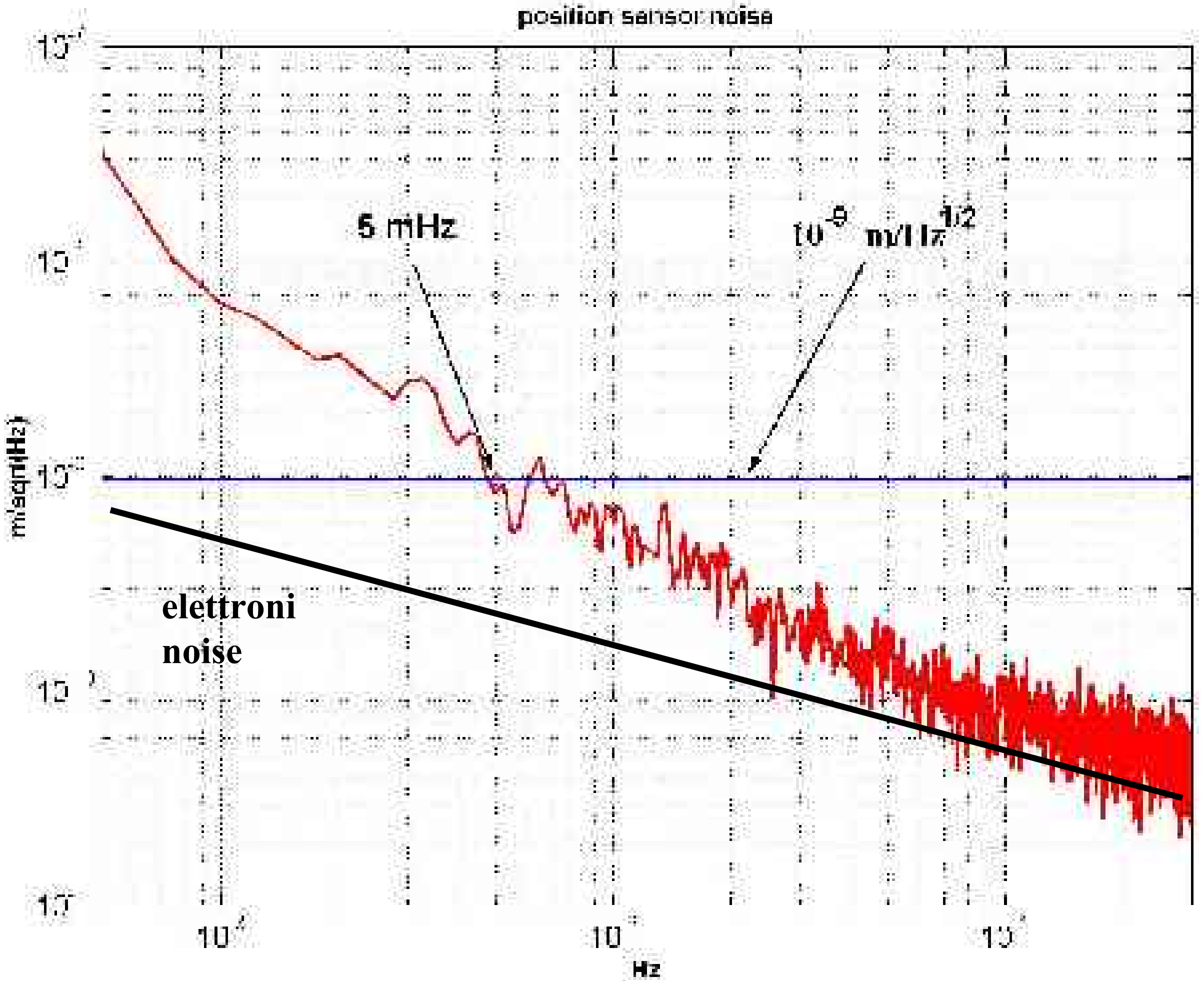
the system is symmetric for differential measurements

the whole set-up is closed in a box to reduce thermal variations and prevent effect of air flows etc.

Preliminary results (single arm)

beam power 140μW

spot size 350 μm



Radiation pressure

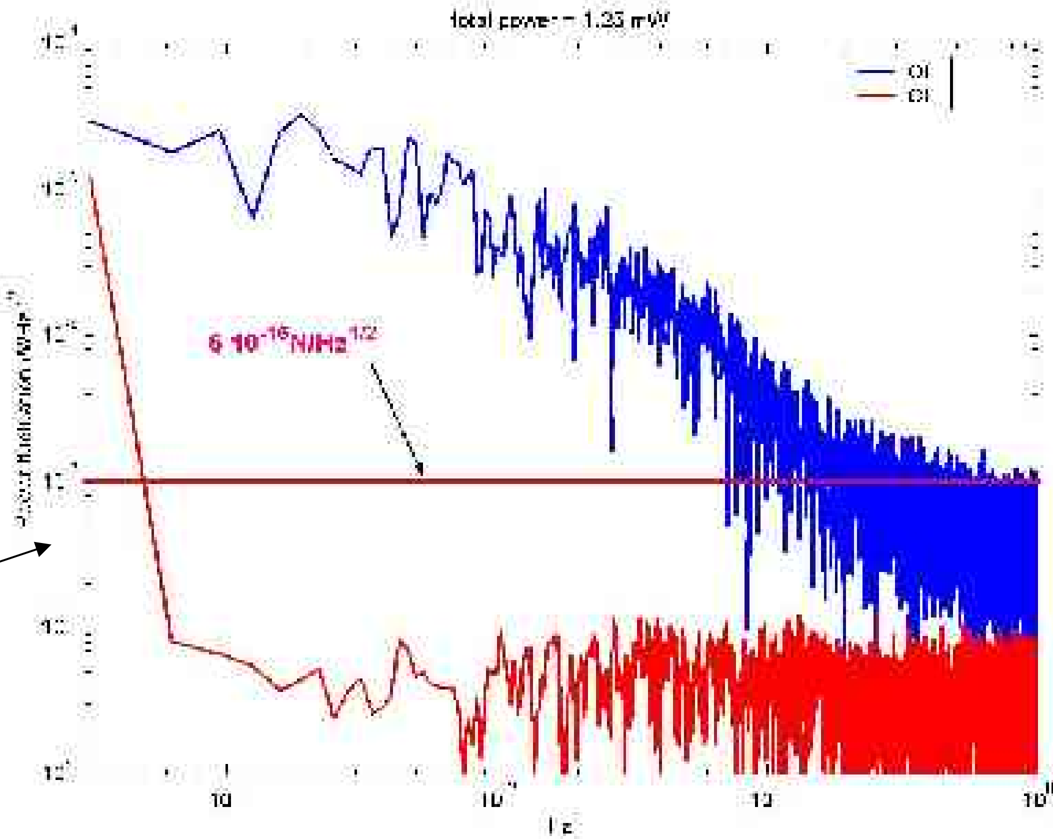
The DC force is very small and can be compensated electrostatically

$$F \le \frac{2 \cdot P}{c} \approx 6 \cdot 10^{-12} \left(\frac{P}{1\text{mW}} \right) [N]$$

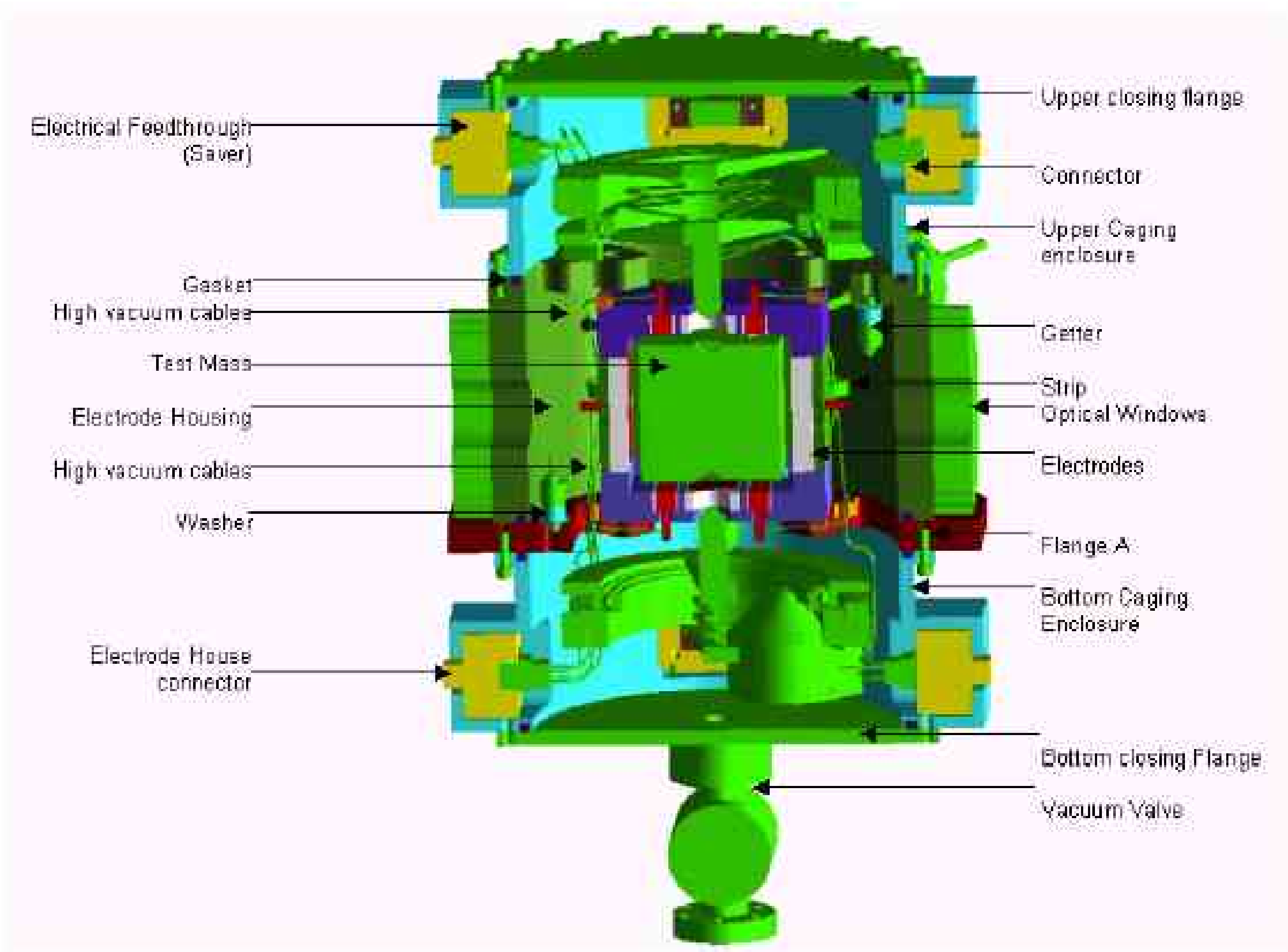
The force due to power fluctuation can be reduced within the specification by active stabilization

example:

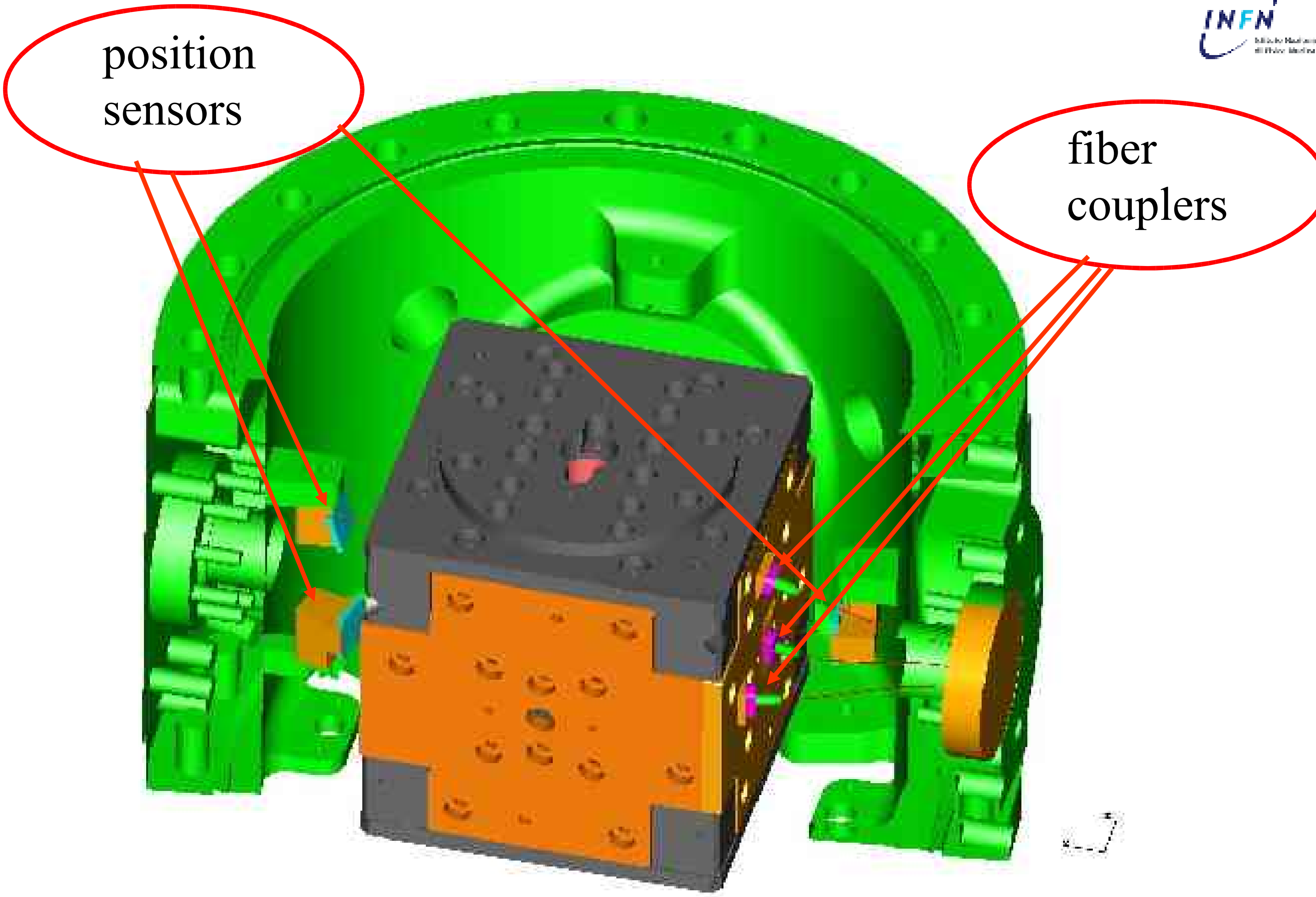
laser diode
total power 1.2 mW
feed-back on laser current

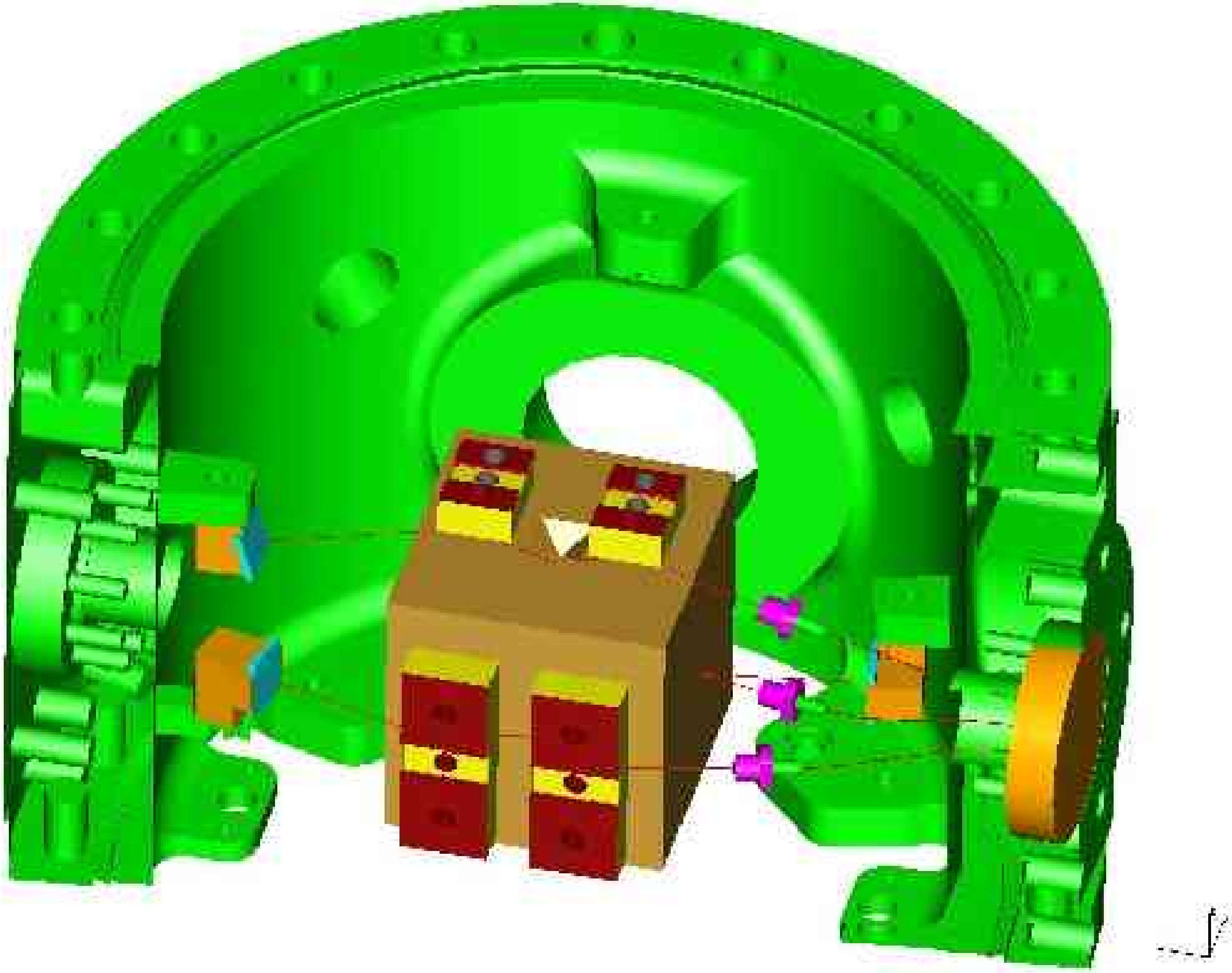


Integration in LISA

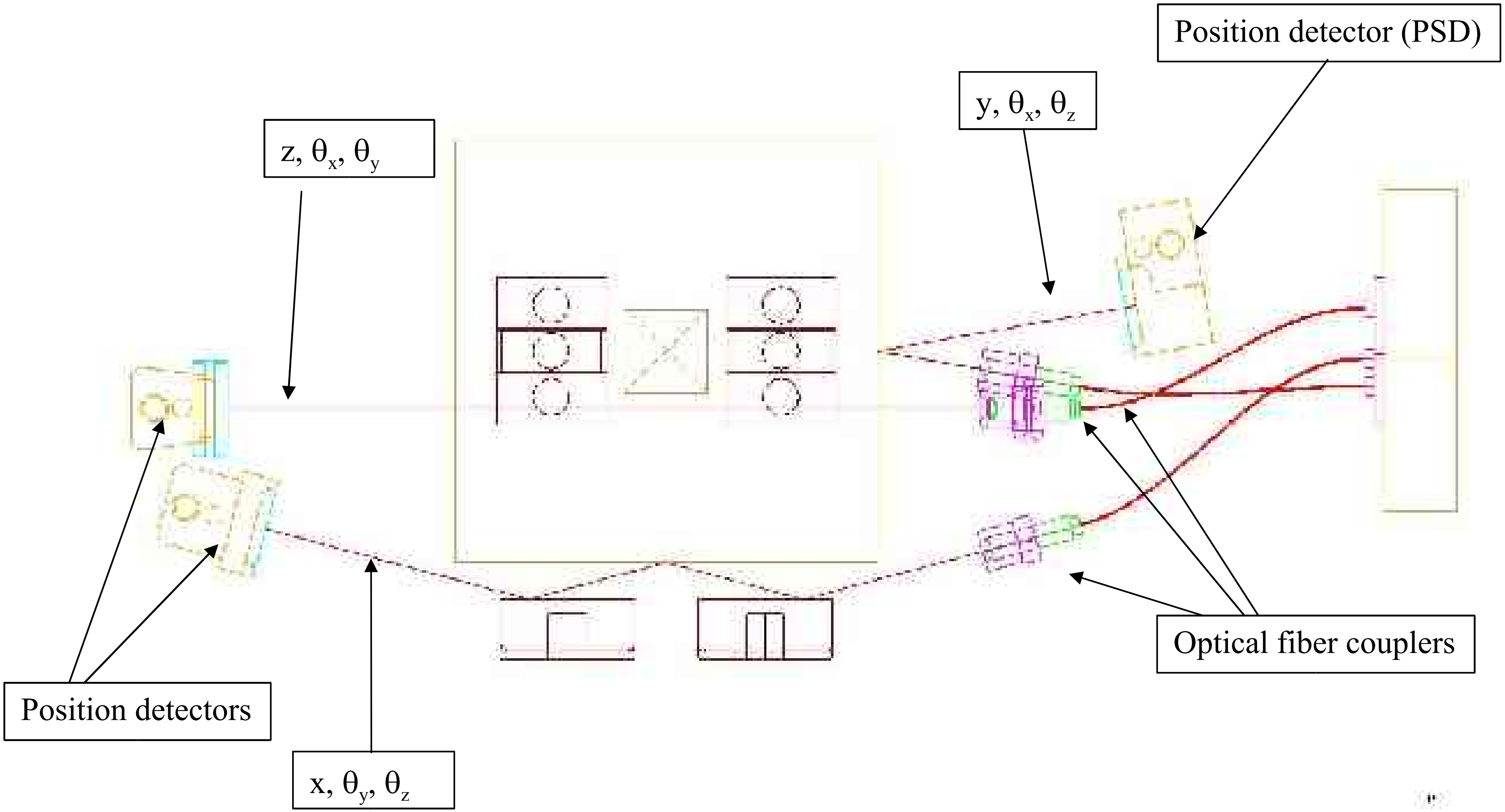


Schema del modello ingegneristico del sensore inerziale


position
sensors
fiber
couplers

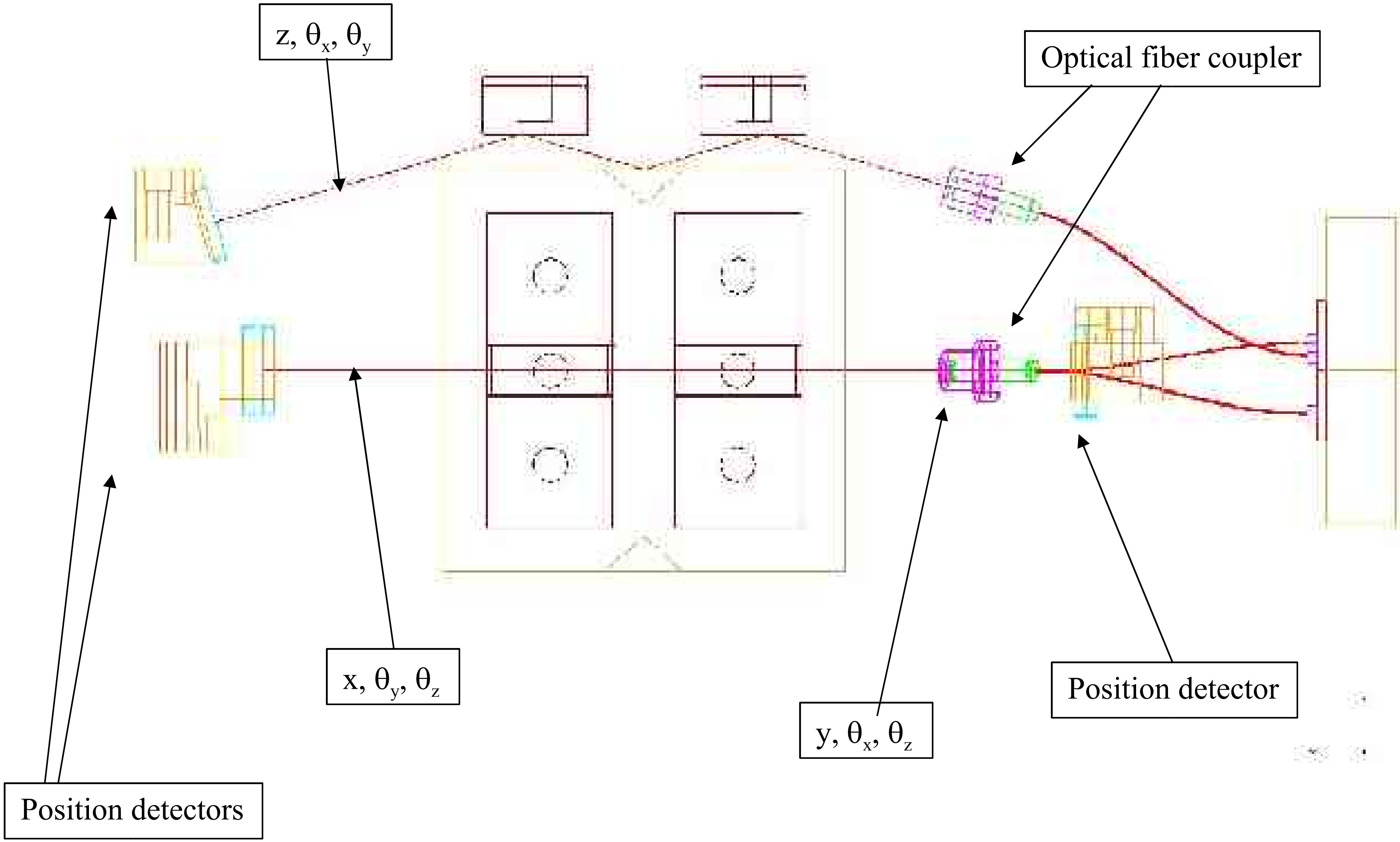


Top view



Position detector (PSD)
y, θ_x, θ_z
z, θ_x, θ_y
Optical fiber couplers
Position detectors
x, θ_y, θ_z

Front view



z, θ_x, θ_y
Optical fiber coupler
x, θ_y, θ_z
y, θ_x, θ_z
Position detector
Position detectors

CONCLUSION

- An optical readout based on optical levers is potentially compliant with LISA GRS specifications
- Preliminary bench-top experiments show a sufficient sensitivity down to 5 mHz – work is in progress
- We have a principle design for the integration in LTP (?) and LISA
- Still there are several technical aspects to be defined
- We plan to test a prototype on the Trento torsion pendulum next year