An Optical Read-Out system for the LISA gravitational reference sensor: present status and perspectives.

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INTRODUCTION

Since a few years, the LISA group in Napoli has been working to the development of an Optical Read-Out (ORO) system, based on optical levers and position sensitive detectors, for the LISA Gravitational Reference Sensor (GRS). This is intended as a more sensitive extra sensing device, in addition to capacitive readout that is the reference solution already tested on flight by the LISA-Pathfinder mission. The reliability of the proposed ORO device and the fulfillment of the sensitivity goals have been already demonstrated in bench-top measurements and tests with torsion pendulum facilities. In this paper we report on the present status of this activity, presenting the results obtained so-far and the perspectives for the future LISA mission.

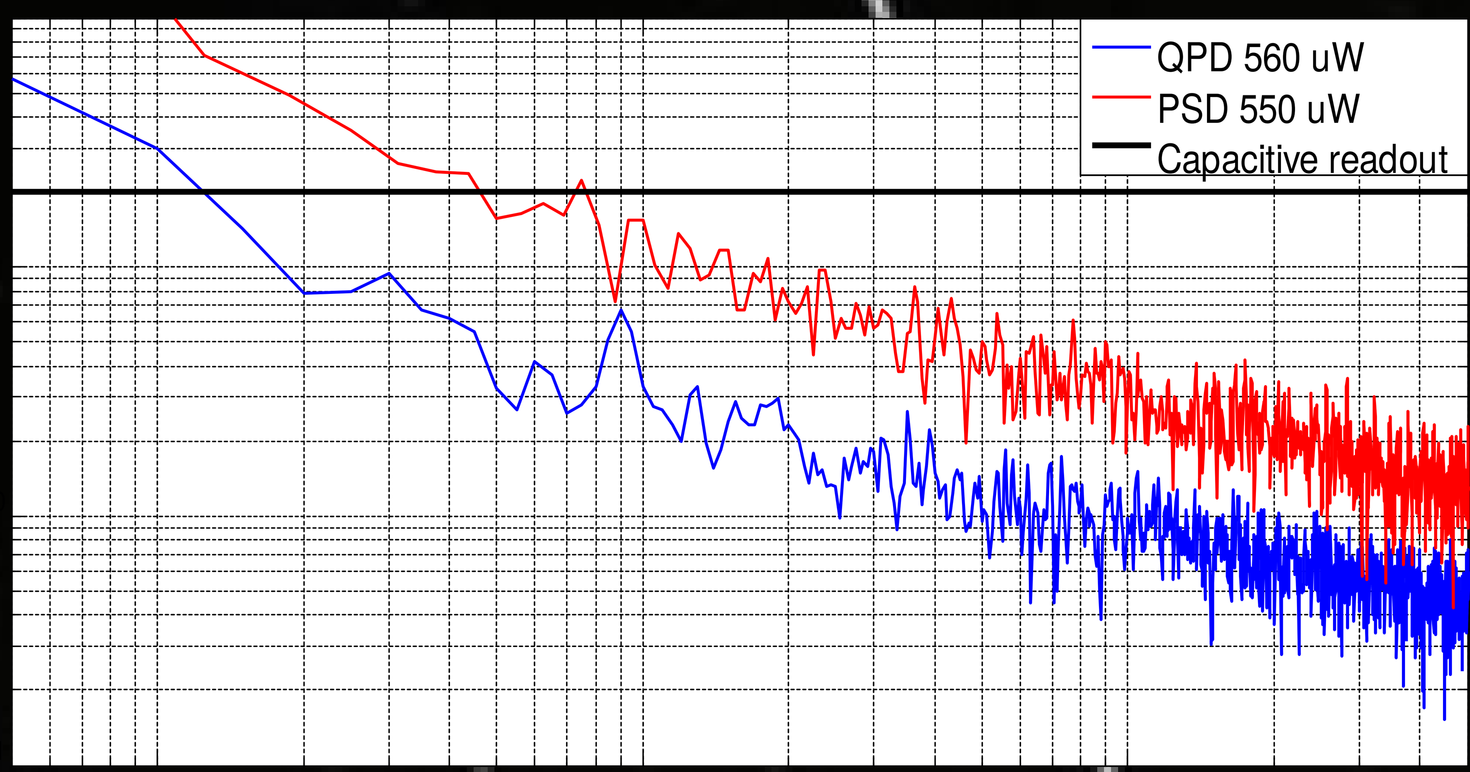
Motivation

Development of an Optical Read-Out system for the LISA inertial sensor, to be integrated in the GRS, together with the capacitive sensor in order to achieve:

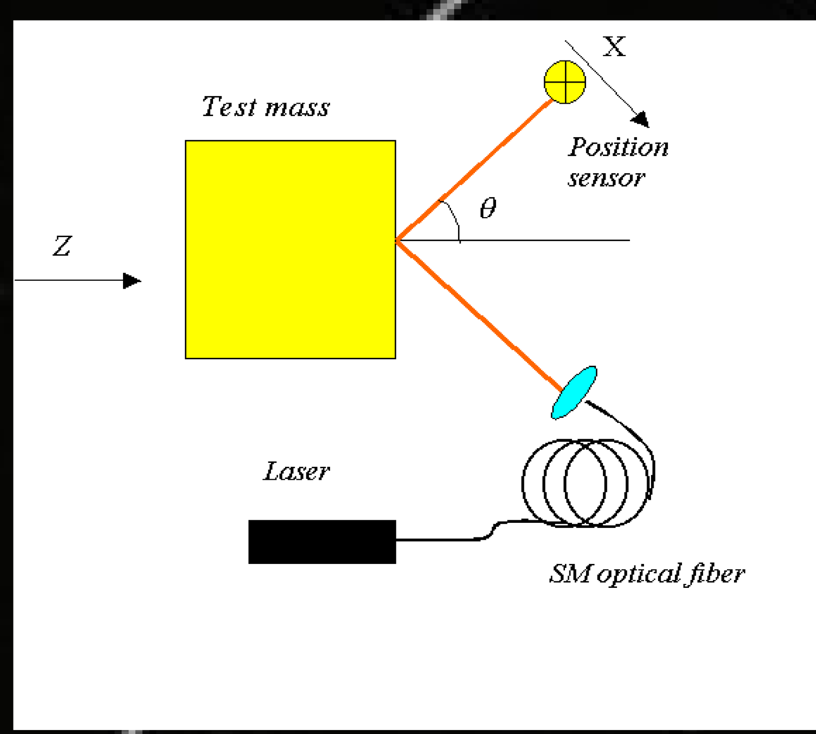
- Risk reduction: a back-up sensor in case the capacitive one fails after the launch;
- Improved sensitivity: relaxed specifications on actuation cross couplings - Present requirement on C.C. is 0.1 % that is a very strong specification.

Sensor Set-up

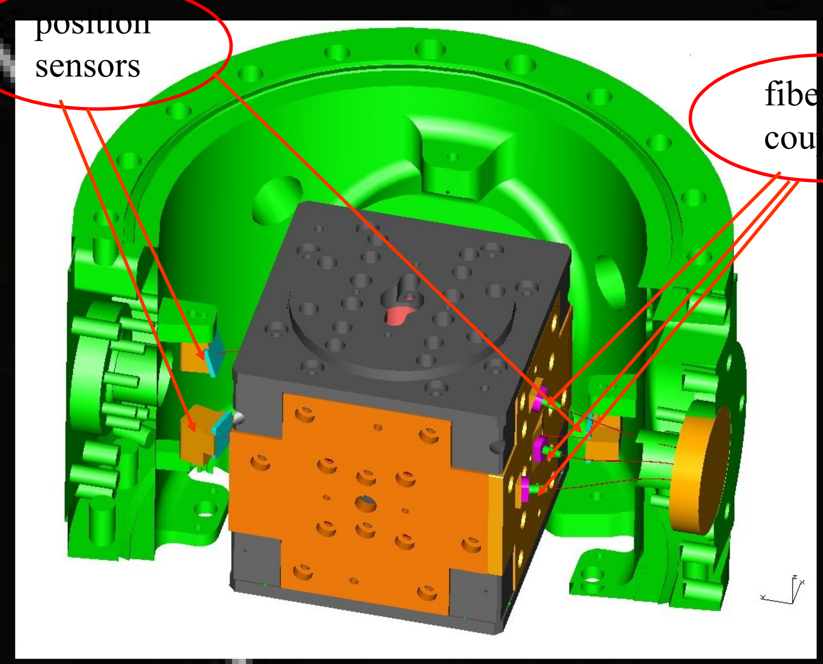
Schematic drawing of the ORO sensor. A light beam is sent trough a SM optical fibre to the test mass and the position of the reflected beam is measured with a position sensor (Quadrant photodiode or PSD). The sensitivity depends on input power, measurement range (beam size for QPD or detector size for PSD) and geometry. With a suitable combination of beams and sensors we can recover the six DOF of the test mass.



ORO sensitivity with different photodetectors.



Schematic of the ORO sensor



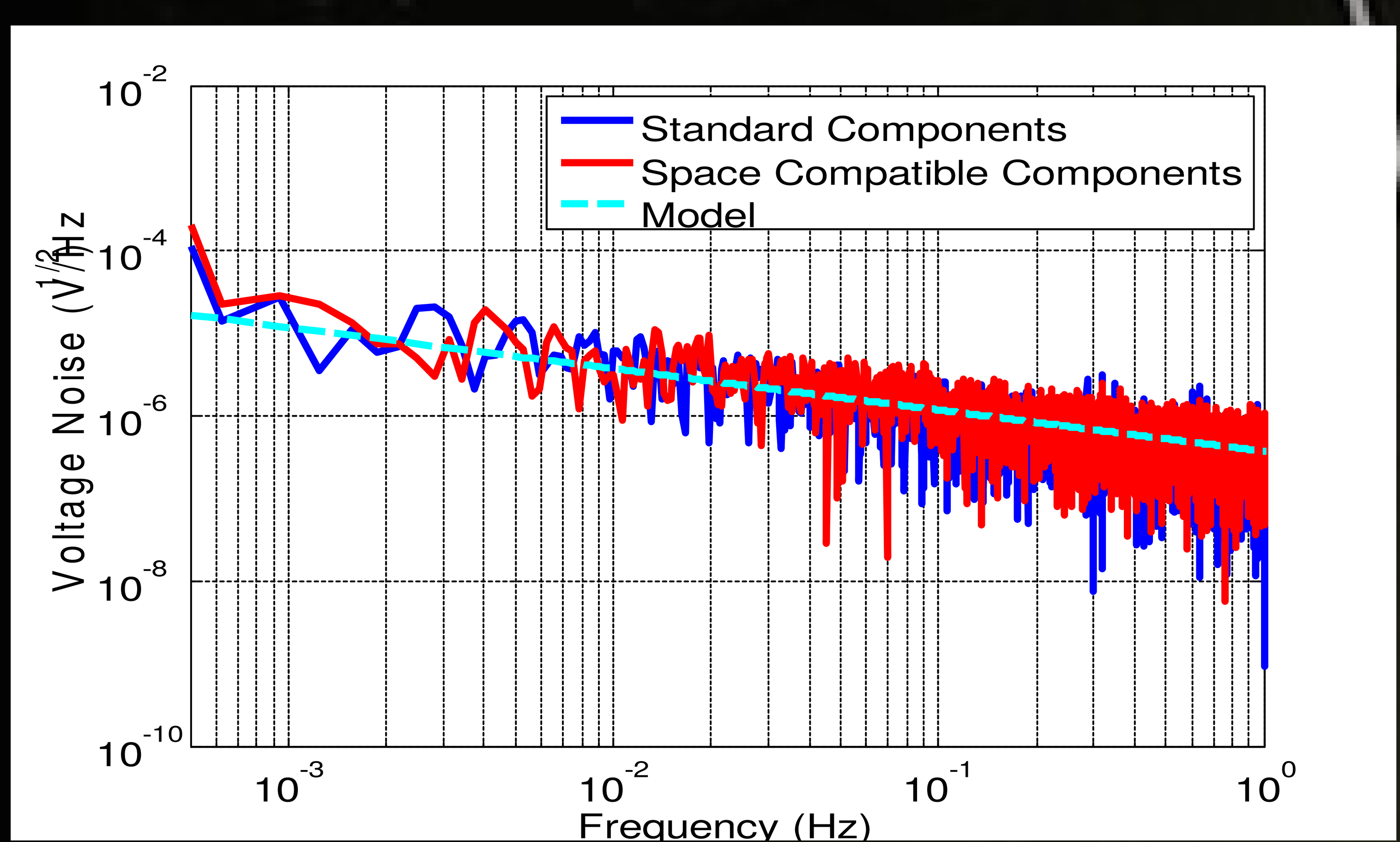
Proposed solution for integration in LISA. The idea is to use the electrodes as mirrors for directing the beams to the test mass surface and to the sensors.

Sensitivity

The figure above shows the comparison between ORO and capacitive displacement sensitivities. The results for two type of photodetectors, for bench-top measurements, are reported. The measurement ranges are 0.4 mm for QPD and 4.7 mm for PSD. In both cases the ORO sensitivity is limited by the input trans-impedance amplifier current noise.

Space qualified front-end electronics

We verified noise characteristics of Space Qualified (SQ) front-end electronics. The electronic used for processing QPD signals is based on OP27EP. There is a SQ equivalent component OP27AJ/QMLR. The noise performance are exactly the same as the standard components. Il looks that PD readout will not be a problem.



Comparison between standard and space qualified front end electronics

Possible implementation in LISA

Proposed solution for integration in LISA. The idea is to use the electrodes as mirrors for directing the beams to the test mass surface and to the sensors. We tested the 3 beam configuration with a prototype. We used an angular PZT stage and a 3 axial linear PZT stage to check 5 DOFs out of 6 (X, Y, Z, a, q).

The analytical model was validated by tests with a bench-top prototype moved with PZT actuators with calibrated capacitive readout.

The measured matrix element coincide, within a few percent, with the computed ones (compatibly with the prototype machining and assembling tolerances).

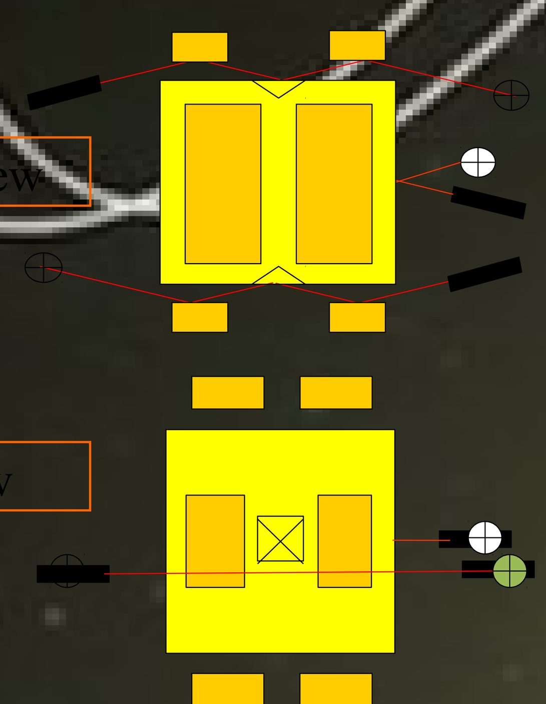
Measured sensing matrix with 5 DOF.

$$\begin{pmatrix} Y_h \\ Y_v \\ Z1_h \\ Z1_v \\ Z2_h \\ Z2_v \end{pmatrix} = \begin{pmatrix} 0.0053 & -0.0007 & 0.0026 & 0.0021 & ? & 0.0551 \\ -0.0293 & 0.3433 & -0.0222 & 0.0512 & ? & -0.0041 \\ 0.0277 & -0.0001 & -0.0003 & -0.0002 & ? & -0.0004 \\ 0.0778 & -0.0007 & -1.9028 & 0.1123 & ? & 0.0005 \\ 0.0162 & 0.0005 & -0.0004 & 0.0004 & ? & 0.0004 \\ 0.0283 & -0.0134 & 1.9106 & 0.0964 & ? & 0.0029 \end{pmatrix} \times \begin{pmatrix} X \\ Y \\ Z \\ \alpha \\ \eta \\ \theta \end{pmatrix}$$

Analytical model.

$$\begin{pmatrix} Y_h \\ Y_v \\ Z1_h \\ Z1_v \\ Z2_h \\ Z2_v \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0.0538 \\ 0 & 0.3473 & 0 & 0.0546 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0281 & 0 \\ 0 & 0 & -1.9225 & 0.1020 & 0.0115 & 0 \\ 0 & 0 & 0 & 0 & -0.0281 & 0 \\ 0 & 0 & 1.9225 & 0.1020 & -0.0115 & 0 \end{pmatrix} \times \begin{pmatrix} X \\ Y \\ Z \\ \alpha \\ \eta \\ \theta \end{pmatrix}$$

Front view

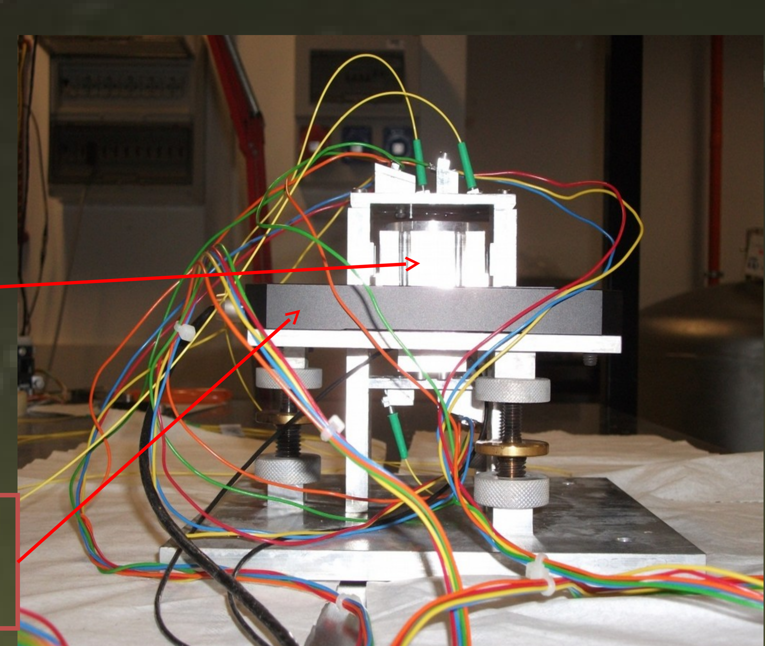


Top view

Schematics of 5 DOF (Z, Y, a, h,) readout system using 3 beams

TM with X,Y,Z PZT actuator inside

Calibrated α,θ PZT actuator



Bench-top prototype for 5 DOF measurements

Conclusion

Both bench top and suspended tests confirm that the ORO sensitivity can be better than the capacitive one, above 1 mHz. The noise level is well characterized and allows to make predictions and trade-off between sensitivity and measurement range. There are possible layouts for the integration in the present design of the GRS, verified with bench-top models. Study of space compatible parts is just started: read-out electronics is not a problem. Next step would be the search for space qualified optical components. The ORO has been developed up to TRL 4 and is a good candidate as a back-up sensor for the LISA inertial sensors, with possible sensitivity improvement.

References

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- *Astroparticle Physics, Volume 34, Issue 6, p. 394-400 (2011)*