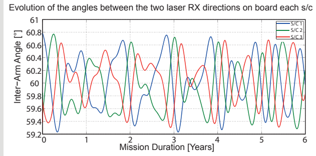
Performance-Verification of In-Field Pointing for eLISA

C. Brugger[1], E. Fitzsimons[1], U. Johann[1], W. Jonke[2], S. Nikolov[1], M. Voert[2], D. Weise[1], G. Witvoet[2]

[1]Airbus Defence and Space, 88090 Friedrichshafen, Germany
[2]TNO Optomechatronics, 2600 AD Delft, Netherlands

Introduction to In-Field Pointing

Evolution of the angles between the two laser RX directions on board each s/c



Orbital dynamics lead to seasonal changes in the shape of the triangular constellation. This "constellation breathing" has to be compensated actively.

Within the eLISA Mission, orbital dynamics will cause the shape of the constellation to change over a period of one year. As a result, the angle between the interferometer arms varies by of order ±1° on an annual timescale and must be actively compensated for. Most studies looking at eLISA type missions typically feature the Telescope Pointing concept - articulating the two telescopes with a mechanism and adjusting the entire payload to compensate.

One possible alternative concept which has been studied in the LISA Mission Formulation study carried out by Astrium Satellites Germany (now Airbus DS) is to utilise In-Field Pointing (IFP). With IFP, a small mechanism would tilt a mirror positioned at an internal intermediate pupil of a (wide field) telescope, thus providing the required pointing corrections.

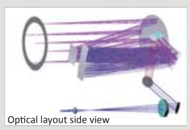
Advantages of In-Field Pointing:

- Only a small mirror needs to be actuated (instead of a full Moving Optical Subassembly)
  - → Full on-ground testability of pointing actuation and associated effects possible
- Telescopes can be rigidly attached to a common, single OB serving both arms
  - → Back-link fiber is avoided
- With IFP the concept of a Single Active GRS per s/c can be realized more easily
  - → Full drag free control of the translational DoFs (no electrostatic suspension in any translational DoF required)
- Potential savings in payload mass, volume and power consumption

Key Objectives

The key objective is an end-to-end experimental validation of the IFP concept to demonstrate its feasibility. The experiment will feature a representative wide field off-axis telescope with a prototype In-Field Pointing Mechanism and a heterodyne interferometer to measure the performance aspects.

Measurement and performance aspects:



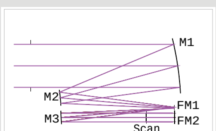
Optical layout side view

- → Passive stability of the IFPM
- → Dependence of the optical path length through the mechanism itself and the telescope surfaces on the pointing angle
- → Piston generated directly at the mechanism and due to systematic beam steering over the mirror topography within the telescope
- → Coupling of the pointing jitter to local topography gradients on the mirror surfaces
- → Impact of misalignments, i.e. geometrical lever arms coupling to pointing jitter

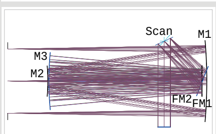
Optical Design

Baseline for the optical design is a fully representative **wide field off-axis telescope** design with an aperture of 15 cm and the following optical features:

- → 1st stage of the optical system: 3 mirrors (magnification 5x) plus 2 folding mirrors producing an accessible intermediate pupil (30mm diameter) at scanner position
- → 2nd stage: Relay system consisting of 2 folding mirrors and commercial lenses (magn. 5x) that produce an exit pupil of 6 mm in diameter
- → On the Interferometer head: 2nd relay systems (1x) for pupil location at the detector plane



Optical layout top view

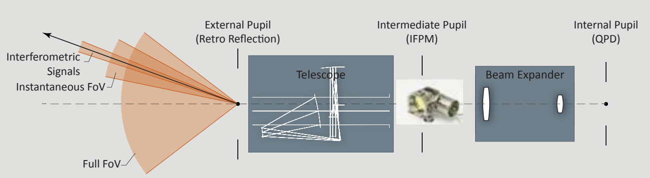


Optical layout side view

Challenges for the telescope and its optical design:

- → Guarantee the required optical performance for the telescope over the entire FoV
- → Provide accessible intermediate pupil plane for positioning of the IFPM
- → Robustness with respect to alignment errors or manufacturing tolerances of the optical components

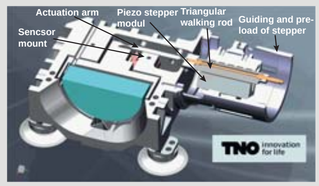
Gaussian Beam Radius	25 mm	5 mm	1 mm
Pupil Diameter ($6w_0$)	150 mm	30 mm	6 mm
Interferometer FoV	±40 µrad ⇨	>10^{-4} Hz @ IFPM 4 nrad/s	ca. ±1 mrad at QPD
Instantaneous FoV	±200 µrad		
Full FoV	±1° (±17mrad)	±5° at IFPM	
Magnification	5x	5x	

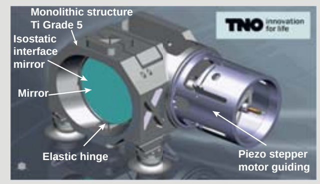


In-Field Pointing Mechanism

After having developed a conceptual design, the In-Field Pointing Mechanism was manufactured and assembled by TNO in the Netherlands. The IFPM is a pointing device in which a stable incident beam is deflected from a flat mirror that can be tilted to accomplish the beam steering over the required range.

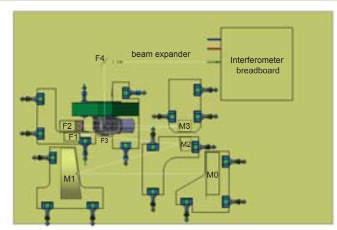
- → The mechanism is based on a monolithic TiAlV structure (~60x70x100mm³, 1kg) with integrated Haberland hinges similar in design to the PAAM
- → Gimbal architecture: Axis of rotation ideally coincides with the mirror surface
  - → Minimal sensitivity of the optical path length to pointing
- → Mirror rotation range of at least ±2.5°
- → Actuation force parallel to mirror surface
  - → Minimized optical path length effects and mirror surface distortion
- → Actuation based on piezo stepper mechanism:
  - → High resolution + large range





Experimental Setup

On the right side a CAD model illustrates the current experimental setup design showing the main elements and the way they are mounted to the large OB (~1200x800mm²) to guarantee an all Zerodur transfer function.

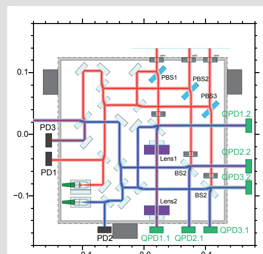


Top view of the current experimental setup design showing the optomechanic mountings for the main elements: Telescope mirrors M0 - M3, folding mirrors F1-F4, IFPM, beam expander (relay sytem) and interferometer breadboard.

To minimize measurement noise the following aspects are taken into account:

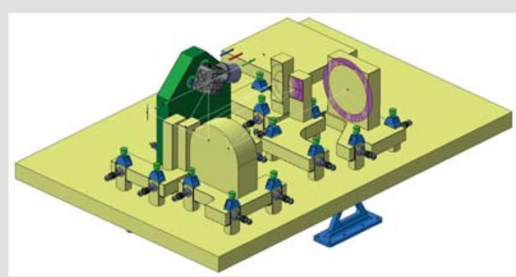
- → Use of Zerodur for critical elements to avoid thermal expansion
- → Compact design and a minimum of transmissive optical elements
- → Optical components of high surface quality

The Interferometer head is an all Zerodur breadboard (270x275 mm²) with a 2nd relay system for pupil imaging on the photodiodes.
The design utilises fiber launchers provided by the University of Glasgow to ensure highly constant beam pointing.



Interferometer Design: 270x275 mm² breadboard made from ultra low expansion glass (Zerodur) and 2nd Relay System for pupil imaging on Photodiode.

In addition to power/intensity and phase stabilization, two measurement and up to 4 reference QPDs are planned. Thus stray light suppression can be achieved by a balanced detection.



LET Laboratory for Enabling Technologies

Performance Verification of In-Field Pointing for eLISA

DLR

TNO innovation for life

Christina.Brugger@astrium.eads.net