International Conference on Space Optics—ICSO 2014

La Caleta, Tenerife, Canary Islands

7–10 October 2014

Edited by Zoran Sodnik, Bruno Cugny, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2014, edited by Zoran Sodnik, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 10563, 105632G · © 2014 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2304102

SIMULATING LASER INTERFEROMETERS FOR MISSIONS SUCH AS (E)LISA, LISA PATHFINDER AND GRACE FOLLOW-ON

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EXTENDED ABSTRACT

Sensing tiny distance variations interferometrically will be a key task in several future space missions. Interferometric detectors such as (e)LISA will observe gravitational waves from cosmic events such as for instance super novae and extreme mass ratio inspirals. The detection principle of such detectors is sensing phase variations due to tiny distance variations between two free floating test masses aboard two remote spacecraft originating from passing gravitational waves.
This detection principle will be tested for the first time by LISA Pathfinder (launch ~2015), where the interferometric readout of two free floating test masses aboard one single spacecraft will be demonstrated.
Future geodesy missions will map Earths Gravity field, by interferometrically measuring distance variations between two spacecraft in low Earth orbit. This will be tested for the first time by the Laser Ranging Instrument (LRI) aboard GRACE Follow-On (launch ~2017).
The low noise laser interferometry of all these missions provides a number of challenging tasks. We will present optical simulations performed for the missions above.

The interferometry of LISA Pathfinder is purely local (there do not exist any received beams from remote spacecraft), such that all beams can be approximated by fundamental Gaussian beams. We will present simulations regarding the coupling of residual test mass jitter (longitudinal and lateral as well as angular) to the phase readout, including Monte Carlo simulations to predict how misalignment affects resulting phase noise and estimate in-flight alignment of the test masses.

In all of the mentioned missions, the local laser beams are delivered to the optical bench by fibers, resulting in laser beams in fiber modes. Besides local laser beams, the interferometry of missions such as (e)LISA and LRI involves also received beams from remote spacecraft. These beams have diameters in the range of tens of meters (LRI) or kilometers (LISA / eLISA and alike), before being clipped down to centimeter scale by the receiving aperture. The resulting top hat beams show strong diffraction effects and are therefore imaged on the optical benches. Key elements for simulations are therefore the propagation with diffraction of top hat beams and fiber modes in vacuum, as well as imaging optics causing aberration and astigmatism, with the central task to characterize the coupling of test mass or spacecraft jitter to optical readout noise, in presence of realistic alignment errors.
A recurring and often limiting noise in the length measurement originates from the cross coupling of angular component jitter. This cross coupling will be briefly introduced with strategies for its mitigation in the various missions.

To overcome the limitations of existing and commercial software, we have written and used for the simulations above as well as for general interferometer design purposes a dedicated software package called IfoCAD which is publicly available and will be presented as well.