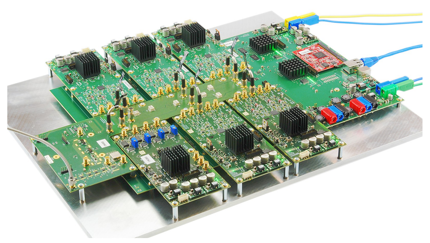
AN OPTICAL TESTBED FOR THE LISA ARM METROLOGY CHAIN

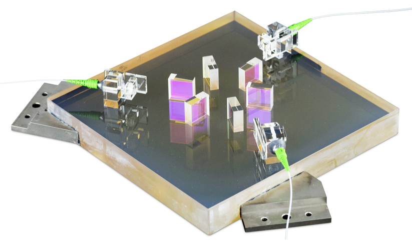
D. Penkert[1], T. Schwarze[2], G. Fernández Barranco[1], O. Gerberding[1], N. Brause[1], I. Bykov[1], G. Heinzel[1,2], K. Danzmann[1,2]

Albert Einstein Institute Hannover [1] Max Planck Institute for Gravitational Physics [2] Leibniz Universität Hannover

Abstract

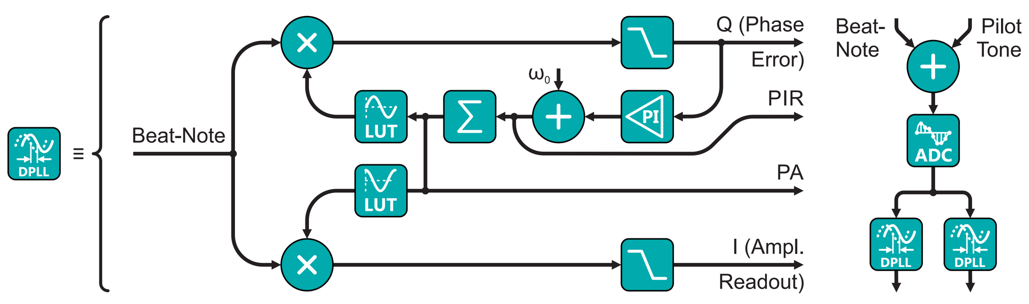


The Laser Interferometer Space Antenna (LISA) will utilize cascaded heterodyne laser interferometry with highly dynamic beat-note signals between roughly 5 and 25 MHz to measure gravitational waves in a range of 0.1 mHz to 1 Hz. The planned readout mechanism is based on an FPGA-driven digital phase measurement system (PMS) capable of tracking these beat-notes with microcycle precision. Prototype hardware has been developed in the scope of an ESA technology development program by a joint venture of DTU Space, Axcon ApS, and the AEI. A key experiment for testing and advancing this phasemeter technology is our ultra-stable, quasi-monolithic "Hexagon" interferometer.



LISA Phasemeter

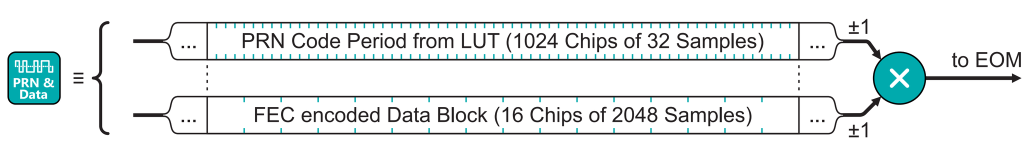
The basic phase readout mechanism uses a digital phase-locked loop (DPLL) to track a signal's frequency (PIR) and phase (PA).



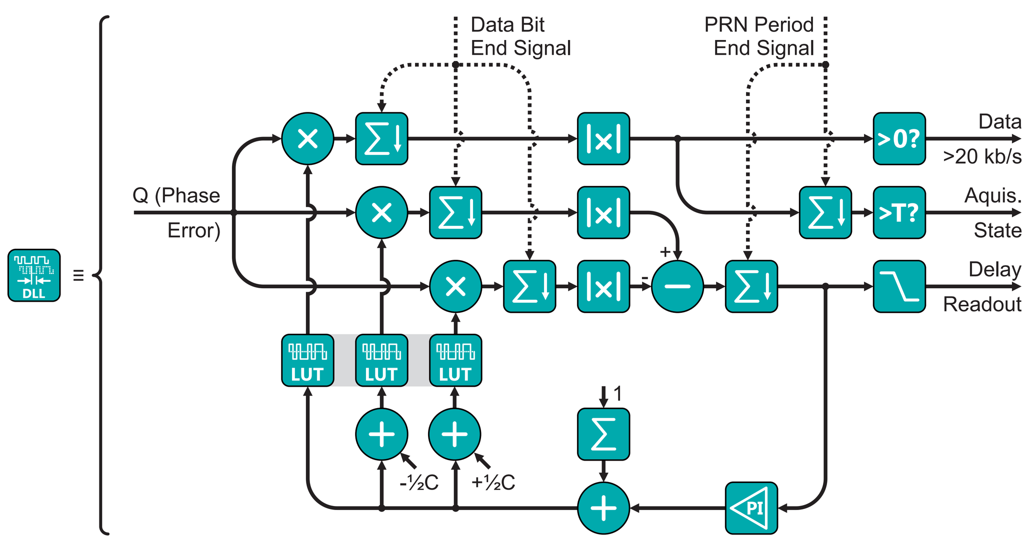
To eliminate relative ADC timing jitter, an analog pilot tone is added to each input channel and tracked by a separate DPLL for dynamically resampling the various beat-note signals during post-processing as a part of the time-delay interferometry (TDI) algorithm.

Auxiliary Functionality

Sub-meter absolute ranging is realized on top of the deep-space network by phase-modulating binary pseudo-random noise (PRN) onto the inter-satellite laser beams. The code streams are yet again modulated with binary data to establish a low-speed data transfer between the three spacecraft.



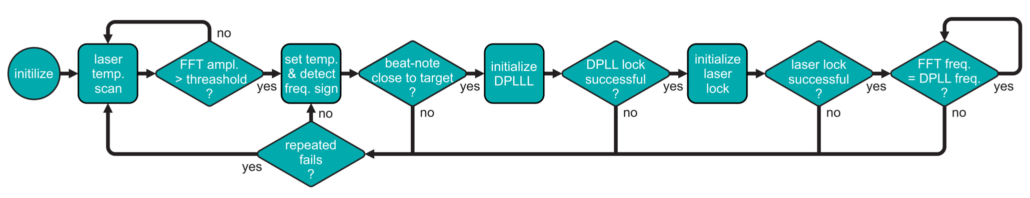
On the receiving side, the PMS will deploy a modified delay-locked loop (DLL) on the DPLL's phase error signal to measure the beam's transit time and simultaneously recover the piggybacked data stream.



(In practice, the binary modulation will also be Manchester-encoded, which was neglected here for simplicity's sake.)

Autonomous Operation

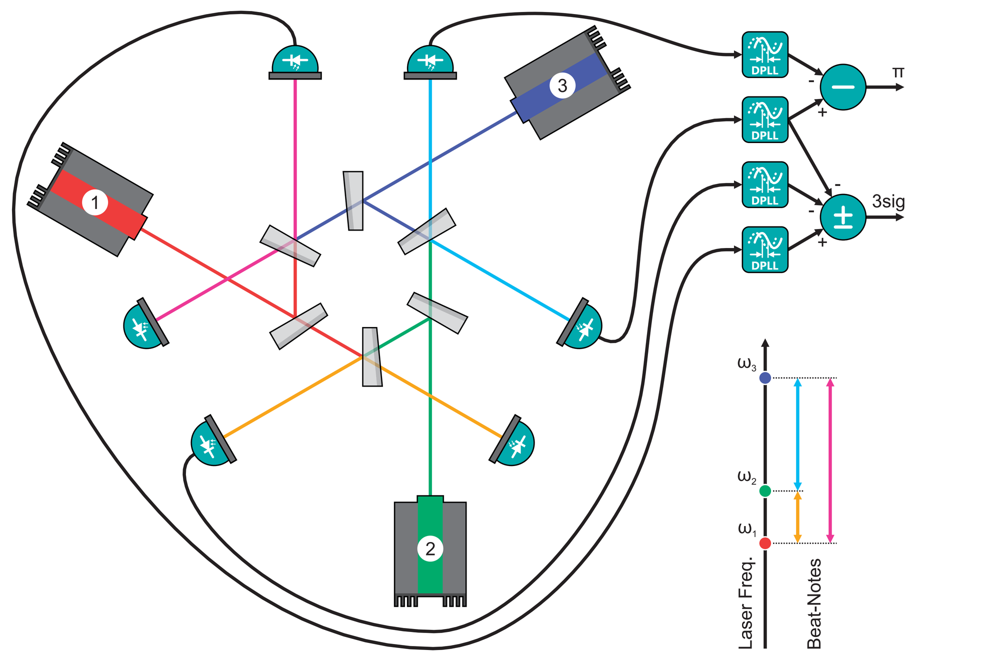
The prototype PMS is equipped with a dedicated FFT FPGA to analyze beat-note frequencies as well as with a DAC board to actuate a laser's crystal temperature and piezo. By these means, it is capable of autonomous DPLL and laser offset locking.



Furthermore, automatic gain controls have been implemented for various control loops throughout the system.

Noise Performance & Linearity Test

The Hexagon implements an optical three-signal generator whose beat-note frequency sum should vanish as long as the three individual signals' phases are properly tracked.

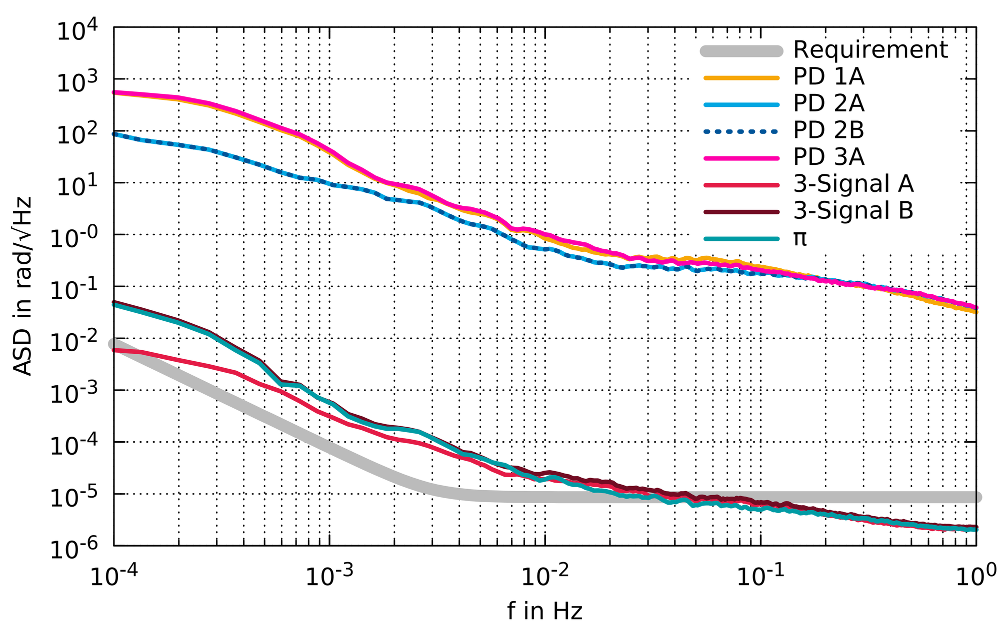


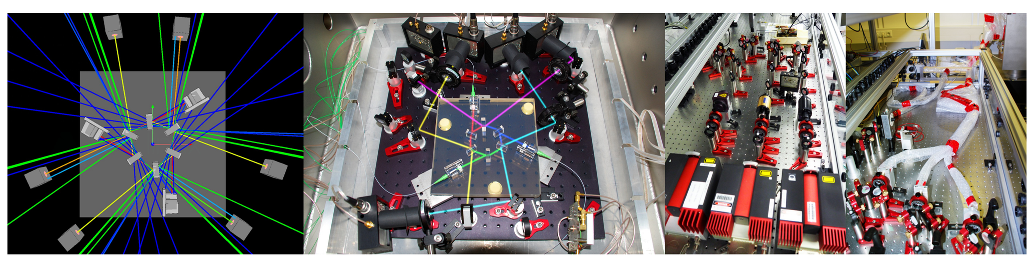
$$(\omega_1-\omega_2)+(\omega_2-\omega_3)+(\omega_3-\omega_1)=0$$

$$\Leftrightarrow\quad(\phi_1-\phi_2)+(\phi_2-\phi_3)+(\phi_3-\phi_1)=\text{const}$$

$$\mathrm{NL}(\phi_1-\phi_2)+\mathrm{NL}(\phi_2-\phi_3)+\mathrm{NL}(\phi_3-\phi_1)\neq\text{const}$$

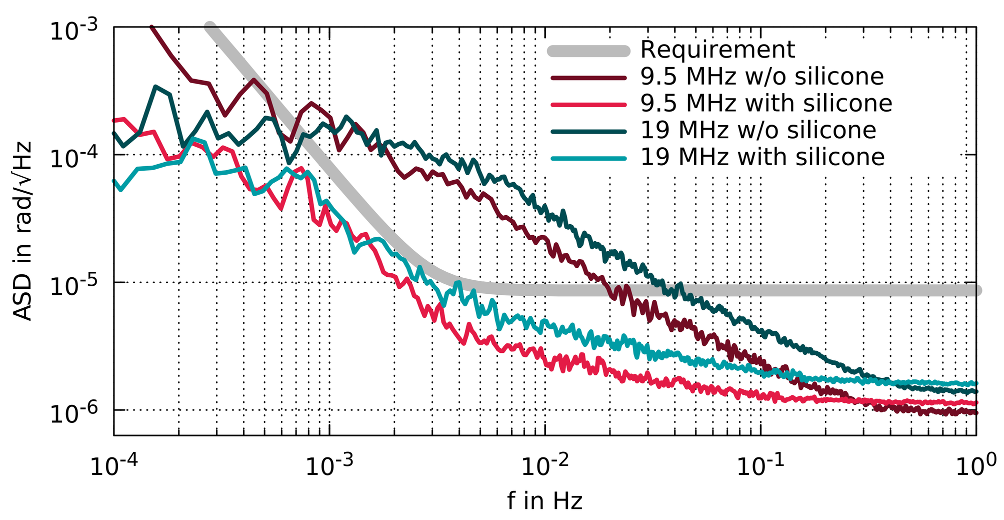
Please note the sensitivity to readout nonlinearities (NL). These are our preliminary results while further improvements as well as our extensive noise hunt are still ongoing.





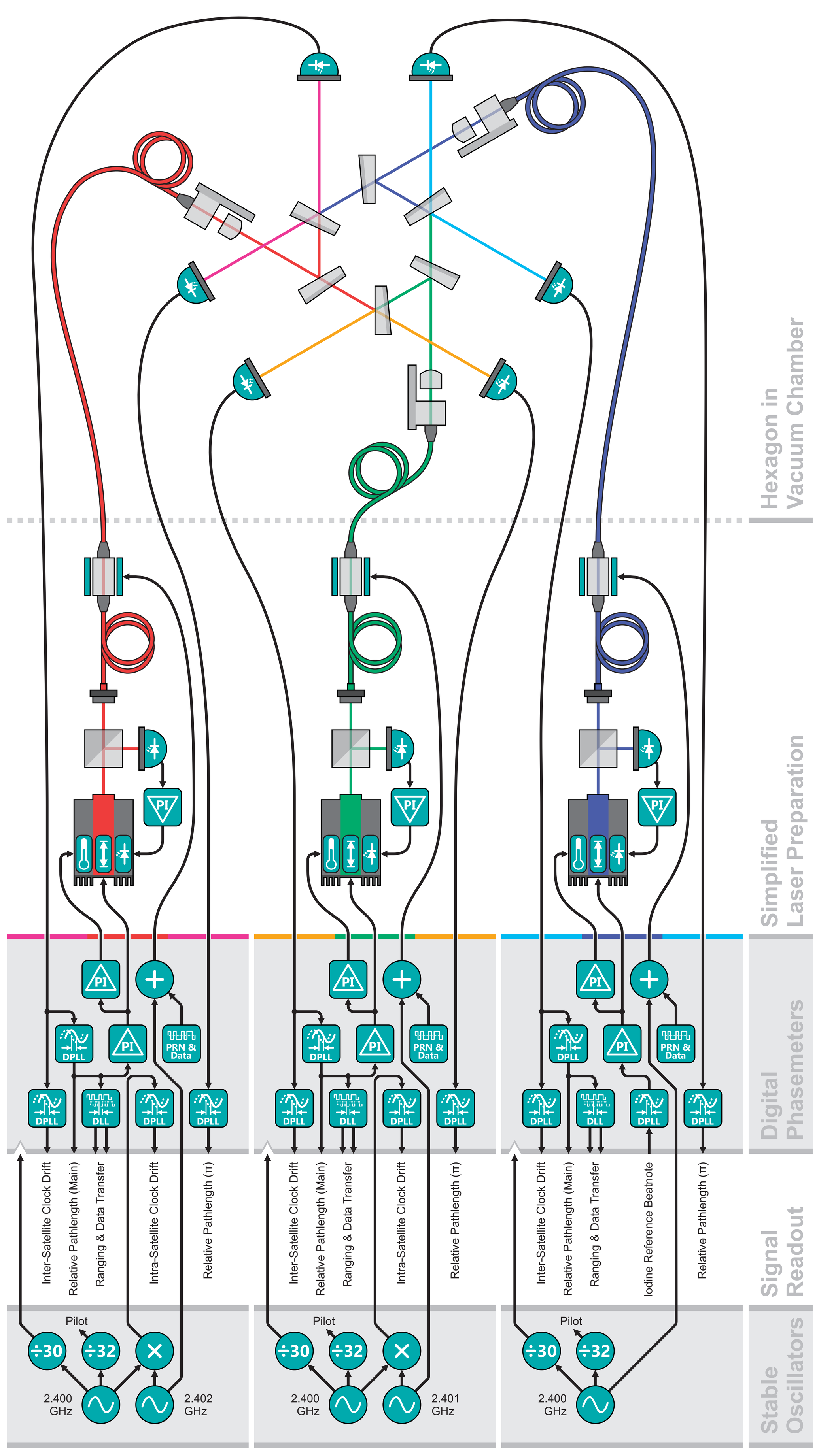
Analog Frontend Improvements

Electrical two-signal split tests with improved thermal coupling between two channels of an experimental frontend by means of industrial silicone coating yield promising results.



Future Full-Scale Experiment

The Hexagon represents a simplified and rigid miniature version of a three-spacecraft LISA constellation and can thus be used to simulate the full LISA arm metrology chain.



The measurements will be performed by three fully independent PMSs connected to each other only via phase modulations imposed onto the three input laser beams.

Also planned, but not shown here, is the deployment of quadrant photodiodes (QPDs) for at least the three primary photo receivers along with the required multitude of corresponding DPLLs in the three PMSs.

Acknowledgements

We gratefully acknowledge support by the European Space Agency (ESA) (22331/09/NL/HB, 16238/10/NL/HB) and the German Aerospace Center (DLR) (50OQ0601, 50OQ1301).

European Space Agency German Aerospace Center Max-Planck-Gesellschaft Leibniz Universität Hannover