Interferometry Development Testbed and TDI

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LISA Science and Engineering Workshop

Hannover September 9-12, 2003

Motivation

- Many areas of the LISA interferometry need to be tested

Interferometry Development Testbed will address a subset of these issued

- The testbed is expandable and reconfigurable to account for changes in the baseline design.

Risk addressed: displacement sensitivity

- Polarization leakage signal readout
- Low power detection
- Frequency noise cancellation
  - construct time-delay interferometry combinations
  - Implementation and determination of time-delays
  - low-data-rate phasemeter operation
  - phase-locking versus one-way measurements comparison
- Clock noise cancellation

Risks not addressed:

- (telescope) wave-front distortion
- Telescope articulation and point ahead
- Optical fiber noise/power handling
- 16, 33 second delays will not be incorporated

Deliverables

- Deliverables of the interferometry development testbed will be
  - Proof of interferometry concepts
  - Design verification and recommendation
  - Algorithms (but **not** software)

Long term goal (TBD)

- Ultimately, interferometry development testbed may provide characterization and testing of individual payloads.

Testbed topology

- Based around a Sagnac interferometer.
  - inherently insensitive to mirror/component motion at low frequencies.

$$\text{attenuation factor} \sim \frac{2\pi L}{c} f$$

10^{-7} @ f=1 Hz, 10^{-10}@ f=1 mHz

  - allows Sagnac TDI variables to be constructed.

Heritage

- Early experiments demonstrated feasibility of low-power phase locking (University of Glasgow).
- Rigid interferometer has demonstrated LISA displacement sensitivity requirements (JPL).
- Phasemeter development has provided several options (Colorado, Glasgow, JPL). At least one has been validated (to the testbed requirements) in an interferometric test.

TDI tests

- TDI can be thought of as synthesizing an equal arm interferometer.
- Demonstrating absolute magnitude of delay (33 seconds) is not as relevant as demonstrating the accuracy of delay (~tens of nanoseconds).

$$\frac{\delta L}{\Delta L} = \frac{\delta \nu}{\nu}$$

$\delta L = 10\ \text{pm}/\sqrt{\text{Hz}}$

$\delta\nu = 30\ \text{Hz}/\sqrt{\text{Hz}}$

$\nu = 3 \times 10^{14}\ \text{Hz}$

- ΔL = the accuracy of the measurement trigger.
- Focus on triggering the measurements to required accuracy

  ~100 m ≡300ns

- total error for all measurements.

Testbed Plan

- Stage I: 1m Sagnac, one laser (4 meas.).
- Stage II: 1m Sagnac, 3 lasers (12 meas.), simplified TDI (simultaneous measurements).
- Stage III: 15m Sagnac, full-TDI (delay implementation), clock noise cancellation.
- Stage IV: 15m Sagnac, 2 end stations plus 1 payload.

Stage I: Small Sagnac with LISA-style polarization readout.

Risks addressed: Polarization-leakage readout

Low power operation

Approach: Construct a short (~1m round-trip) Sagnac interferometer, with following characteristics:

•Signal readouts to use LISA polarization-leakage local oscillator.

•One laser, frequency (Doppler) shifted by 2 AOMs (10kHz beatnote).

•Both "distant spacecraft" replaced by mirrors.

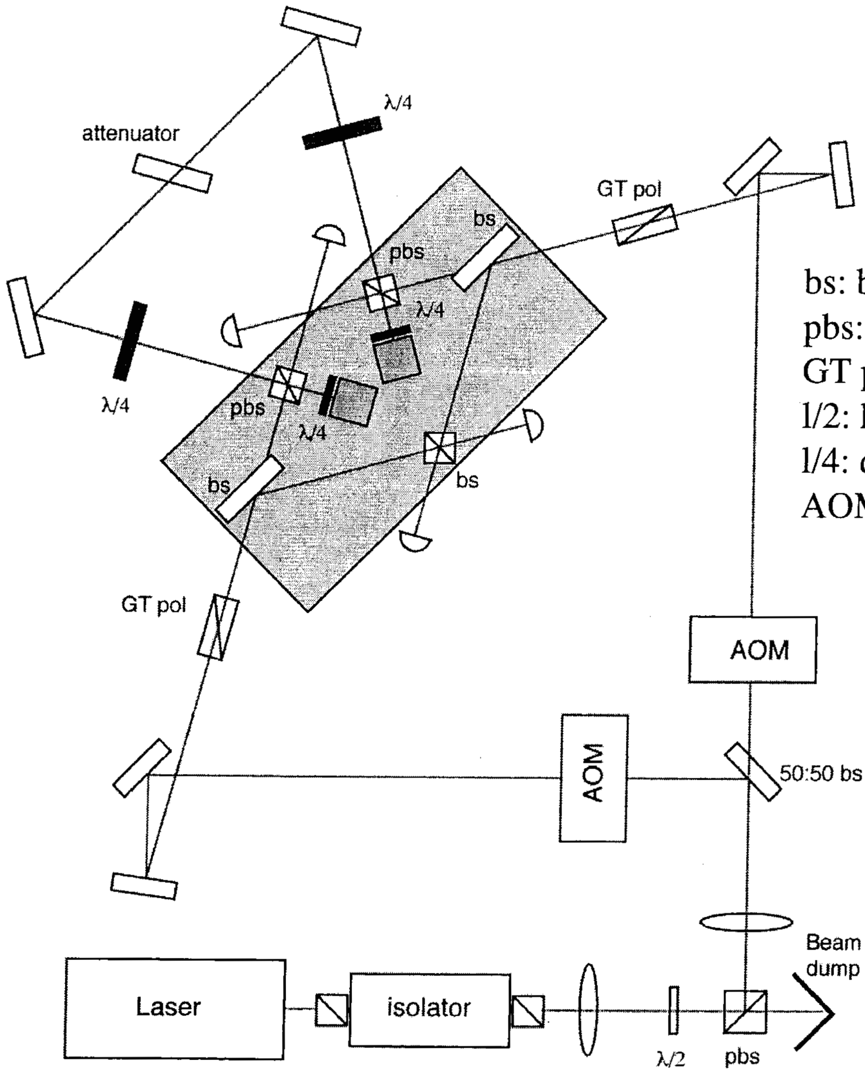
•Test in air, "still air" and vacuum.

•Stage I(a) Use standard (commercially available) 1" optic mounts.

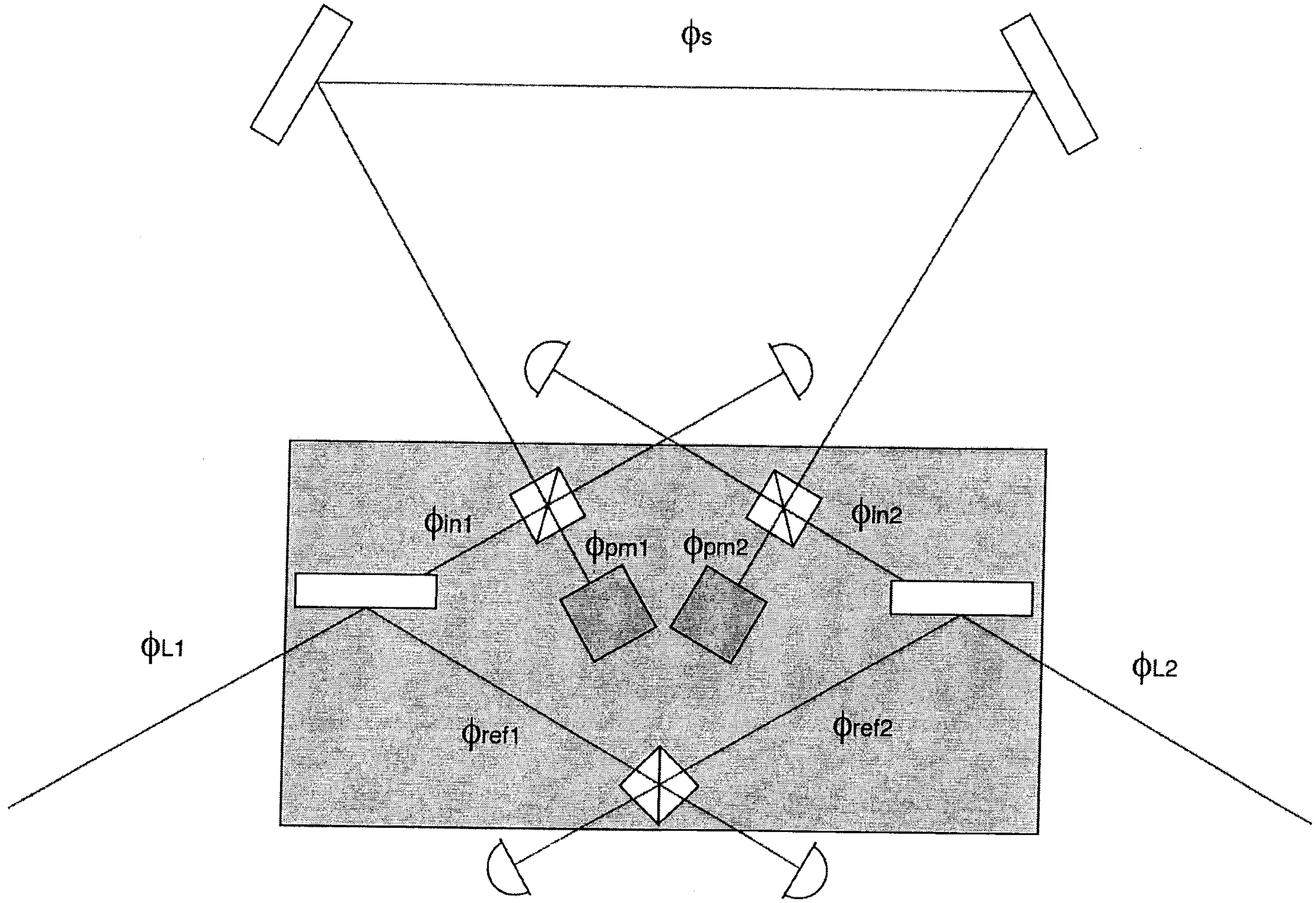
•Stage I(b) Use ULE/fused silica optical components bonded to a ULE slab.

•Stage I(c) Low power (10^{-10} W) signal beams.

Stage I



bs: beamsplitter
pbs: polarizing beam splitter
GT pol: Glan-Taylor polarizer
l/2: half waveplate
l/4: quarter waveplate
AOM: acousto-optic modulator


φs
φin1
φin2
φpm1
φpm2
φL1
φL2
φref1
φref2

Alignment procedure

1. Bond NPBS1, NPBS2 and NPBS3 to bench in approximate positions.
2. Align input beams to optimize interference at PDR1 and PDR2.
3. Bond PBS1 and PBS2 in place in approximate positions.
4. Align Sagnac mirrors M1 and M2 to match return beams into AOM apertures.
5. Insert waveplates and optimize rotation of $\lambda/2$.
6. Align PM1, PM2 and λ /4 rotation to optimize interference at PDS1 and PDS2. Bond PM1 and PM2 in place.

Stage II: Small Sagnac with multiple lasers.

Risks addressed: Construction of TDI combinations

Laser frequency noise cancellation.

Approach: Duplicate vertex 1 set-up at vertices 2 and 3.

•12 simultaneous (one-way) phasemeter measurements.

•Three lasers each frequency shifted by 2 AOMs with 10-20 kHz beat frequencies.

•Low-gain frequency control to keep lasers within 20 kHz.

•Evaluate need for laser frequency stabilization.

•Test in air, "still air" and/or vacuum.

Stage III: Large Sagnac.

Risks addressed: **Implementation of delays**

Optical determination of necessary delays

Low data rate phasemeter operation

Clock noise cancellation

One-way vs. phase-locked comparison

Approach: Accurate triggering of (non-simultaneous) phase measurements.

•Laser frequency stabilization.

•Test in air, "still air" and/or vacuum.

Options

•3 or 6 lasers, auto-alignment system, enclose arms in evacuated beam tubes, optical communications

Receivables

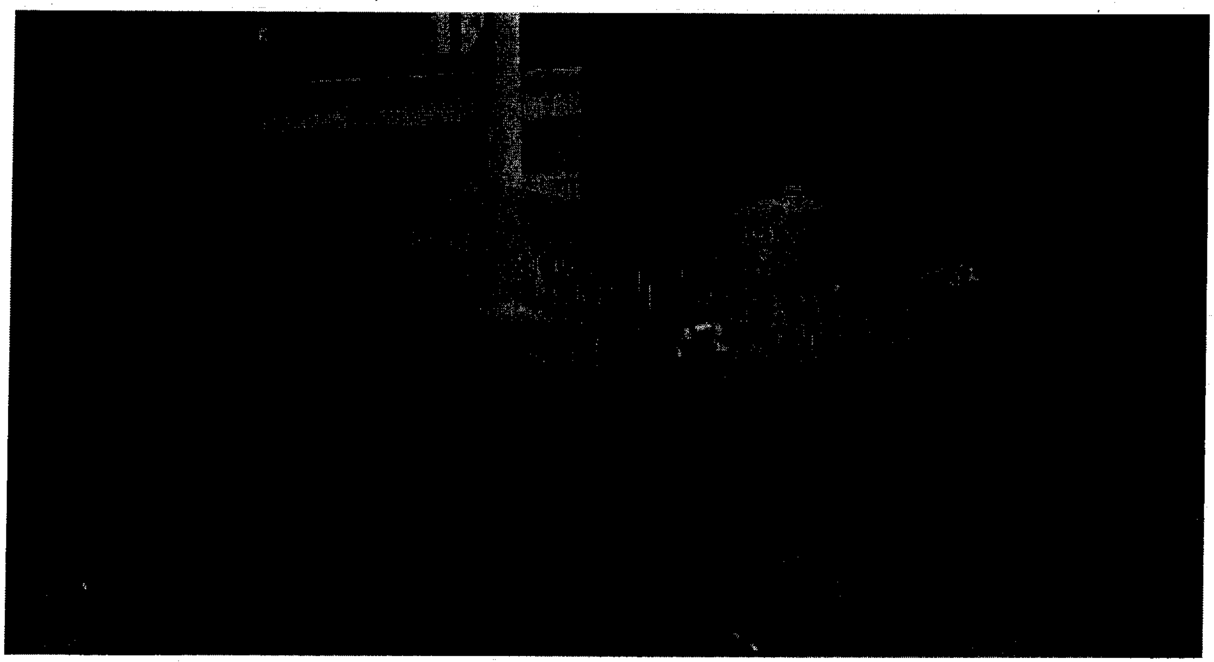
- The testbed will set the schedule for many "receivables".
  - Low-noise, high bandwidth, single- and quad-element photo-receivers.
  - Phasemeter subsystem.
  - Phase-locking controllers.
  - Frequency stabilized laser.
- Schedule TBD.

Personnel/Infrastructure

- 4 FTEs
- Daniel Shaddock, Peter Halverson, Robert Spero, Andy Kuhnert.
- Interferometry and Optical Development High Bay
- Class 10,000 clean room.
- 2 adjacent isolated pads. Allows scaling to 6m arm length.

Current Status

- Two optical benches in high bay.



- All equipment needed for stage I(a) has arrived.