Measurement of the nonreciprocal phase noise of a single mode polarization maintaining optical fiber

Fiber reciprocity

- Desirable to exchange light between two optical benches
- Benches move → fiber
- Fiber introduces reciprocal phase noise, but can be subtracted
- Nonreciprocal phase noise cannot be subtracted
- Possible sources
  - Travel time effects
  - Light in wrong fiber axis
  - Reflections at fiber ends
  - …?
Tests of the reciprocity

- Two possibilities:
  - Sagnac
  - LISA-like

- First experiments using sagnac setup
  - Phasenoise above LISA requirements
  - Reduction not possible

→ LISA-like setup
Initial Sagnac results

- Noise Level of about
  \[3 \cdot 10^{-3} \text{ rad/Hz}^{1/2}\]
  observed

- External influences investigated:
  - Fiber temperature
  - Electronic noise
  - Polarization inside fiber
  - Reciprocity
  - Coherence length
  - Backscatter
  - Temperature of EOM

![Graph showing phase noise vs. frequency](image)
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**LISA-like setup**

- Sagnac does not show required performance
- Switch to setup closer to actual LISA application
LISA like setup

- Improvements:
  - LISA Pathfinder laser system
  - Vacuum
  - Matched path lengths
  - New photodiode amplifiers
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Comparison of spectra

![Graph showing comparison of spectra with labels: first measurement and improved setup.](image)

- **Frequency [Hz]**
  - $10^{-4}$
  - $10^{-2}$
  - $10^{0}$
  - $10^{2}$

- **Phase noise [rad/√Hz]**
  - $10^{3}$
  - $10^{2}$
  - $10^{1}$
  - $10^{0}$

**Legend:**
- Red: first measurement
- Blue: improved setup

**Diagram Elements:**
- Laser 1
- Laser 2
- Fiber under test
- PLL
- S/W PM
- Component library

**Notes:**
- 200 MHz
- 1.6 kHz

LISA Group AEI Hannover, Germany
http://www.lisa.aei-hannover.de/
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Pathlength noise

- Setup sensitive to changes in pathlength
- Simple IFO for comparison
  - Heterodyne Mach-Zehnder
  - 10 cm Arm length
- Measure pathlength noise
- Add.: Measurement w/o fiber

Zerodur Mach-Zehnder
Pathlength noise

Comparison of pathlength noise

- Fiber
- Aluminium breadboard
- Zerodur breadboard

Pathlength noise $(\text{rad}/\text{Hz})$

Frequency (Hz)

Pathlength noise $[\text{m}/\text{Hz}]$

$10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$ $10^{1}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$ $10^{-11}$
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Measurements without fiber

![Graph showing measurement without fiber](image)

- Red line: Fiber
- Blue line: Air

 Roland Fleddermann, June 18, 2008
Zerodur Interferometer

- Aluminum limits pathlength noise

⇒ Zerodur
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First results with Zerodur Interferometer

Still way above requirements, even worse than Sagnac results
Improvements

- Straylight correction
  - Pi measurements high noise level
  - Straylight must enter measurement
Effect of straylight correction

Fiber nonreciprocity measurements with/without correction

- Fiber w/o cor
- Fiber w/ cor
- null meas w/o (cor)
- null meas w/ (cor)
- $\pi_{\text{ref}}$ (MZ, new PDs)
- 1pm goal

Graph showing phase noise and pathlength noise against frequency.
Polarization control

- Polarization must match fiber axis
  - Different indices of refraction act like waveplate
  - Output polarization state will generally be elliptic and time dependent
- Introduce polarizers into zerodur setup
  - Alignment is difficult
  - Polarimeter needed

![Graph comparing phase noise with and without polarizers](image.png)
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Null measurement

- Measurement without fiber
- Foreseen in design of Zerodur IFO
- Shows noise of setup

![Graph showing comparison between null measurement and fiber measurement with polarization](image)
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Summary

Overview over measurements

Phase noise [rad/√Hz]

Frequency [Hz]

Pathlength noise [m/√Hz]
Measurement of the nonreciprocal phase noise of a single mode polarization maintaining optical fiber

Summary

Overview over measurements

- without corr
- best sagnac
- with straylight corr
- null
- requirement: 1 pm

Graph showing phase noise and path length noise as a function of frequency.
Measurement of the nonreciprocal phase noise of a single mode polarization maintaining optical fiber

Summary

Overview over measurements:
- without corr
- best sagnac
- with straylight corr
- fiber length stab
- polarizers (no fiber stab)
- null
- requirement: 1 pm
Conclusions/Outlook

- Requirements not (yet) fulfilled
  - Made good progress
  - Nonreciprocity observed still limited by setup
  - Backreflection identified as noise source

- Possible ways of improvement
  - Less backreflection (couplers, lenses, fibers, alignment)
  - Better polarization alignment/control

- Next steps
  - Investigate backreflection
  - Try other fiber couplers (LPF Fiber injector prototypes?)
  - Improve polarization alignment (Polarimeter)
  - Other fibers
  - Fiber temperature/length stabilization
Thank you for your attention