LTP Interferometer – Noise Sources and Performance

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for the LTP Optical Bench EM Team

Team:

Prime: EADS ASTRIUM

CLRC	TNO	Max-Planck-Institut für Gravitationsphysik Albert-Einstein-Institut	University of Glasgow	Contraves Space
Pre-Investigations, Optical design & manufacturing	Performance & Environmental Tests	Science, Interferometry, Optical design & tests	Pre-investigations & consultancy	Modulation unit

Pre-investigations

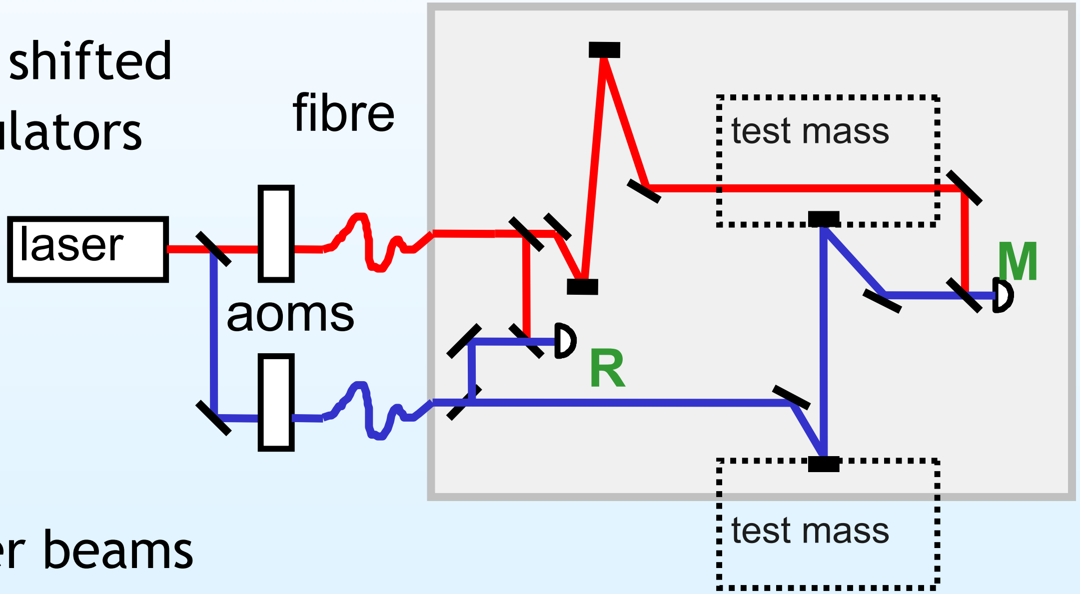
- The pre-investigation work had three main aims:
  - Build a prototype optical bench using hydroxide catalysis bonding
    - Gain experience in the issues involved
  - Install the bonding technology in RAL for EM build
    - Learn from prototype work
  - Demonstrate the stability performance of the prototype optical bench
    - Also demonstrate the performance of LTP heterodyne interferometry

Prototype optical bench

- Aim – demonstrate the suitability of hydroxide catalysis bonding for the construction of the LTP and LISA optical benches
  - Build a test interferometer using hydroxide catalysis bonding
    - Study the procurement and alignment issues involved in constructing a bonded interferometer
  - Demonstrate the displacement stability at as close to the LTP displacement noise goal as possible
- Approach
  - Rigid interferometer – no moveable mirrors
  - Non-polarising heterodyne interferometer
  - Simplest possible layout
  - Zerodur baseplate, fused silica beamsplitters and mirrors

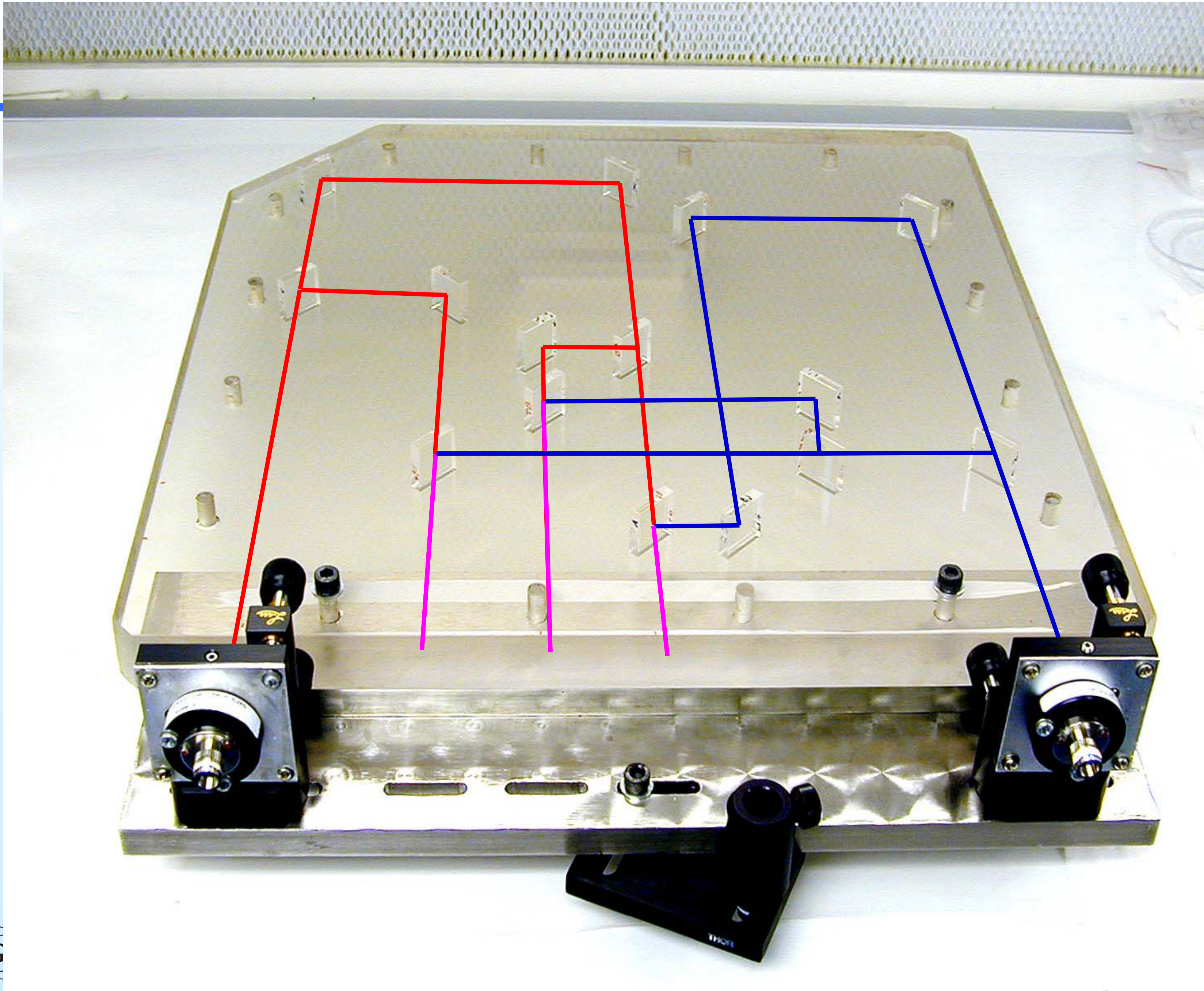
Heterodyne interferometry

- Original laser frequency shifted by 2 acousto-optic modulators (aoms)

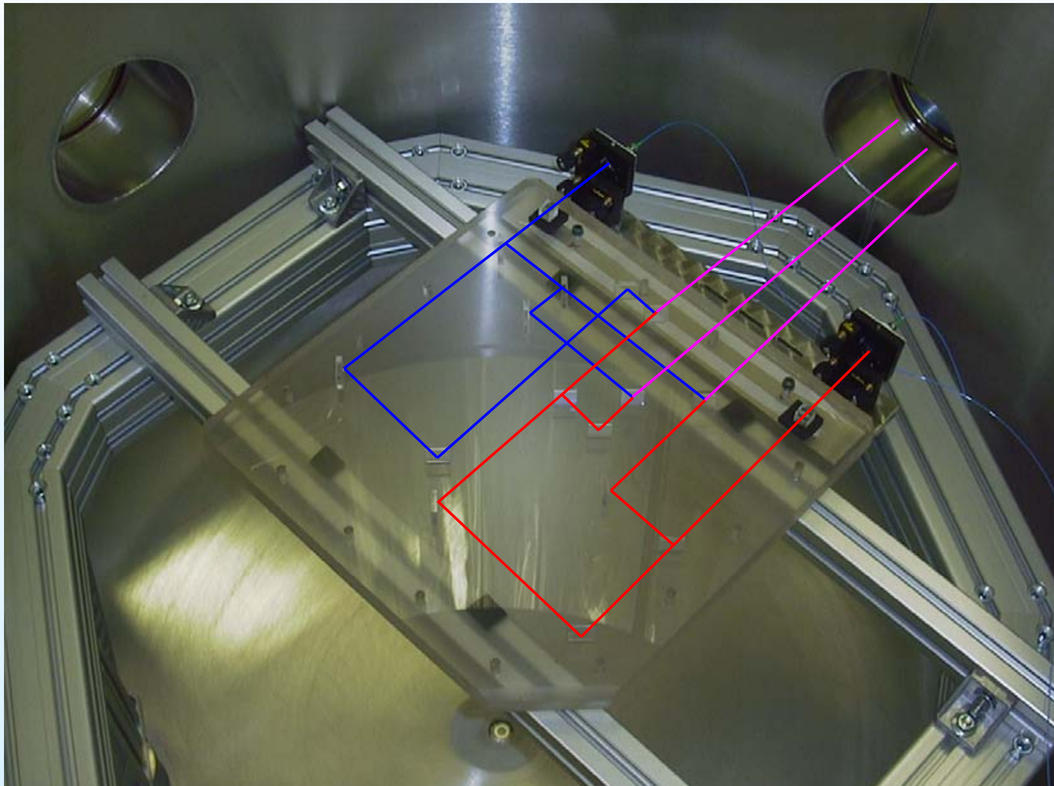


- This generates 2 laser beams with a known frequency offset $\Delta\upsilon$
- At each photodiode we get a signal at a frequency $\Delta\upsilon$

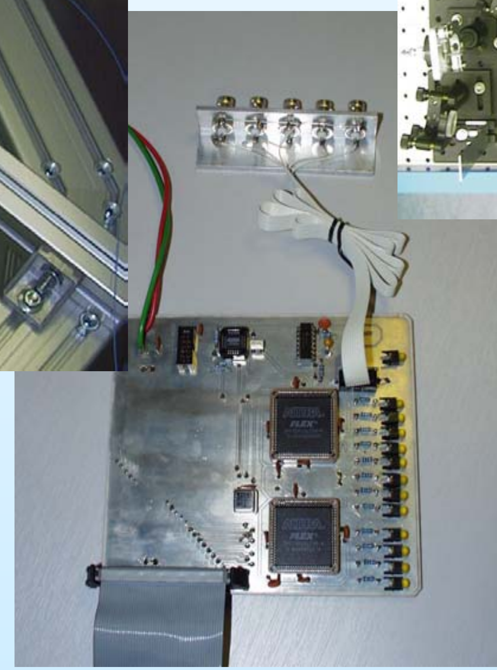
- Output signal is the phase difference between R and M of the signal at $\Delta\upsilon$



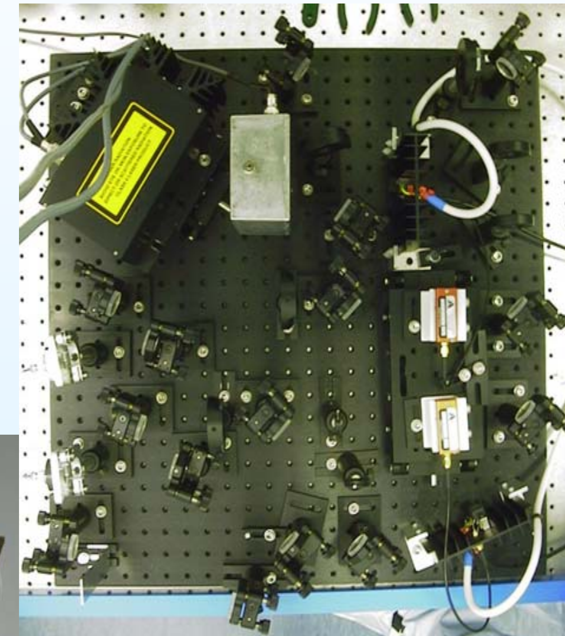
Interferometry tests



Optical bench in vacuum tank

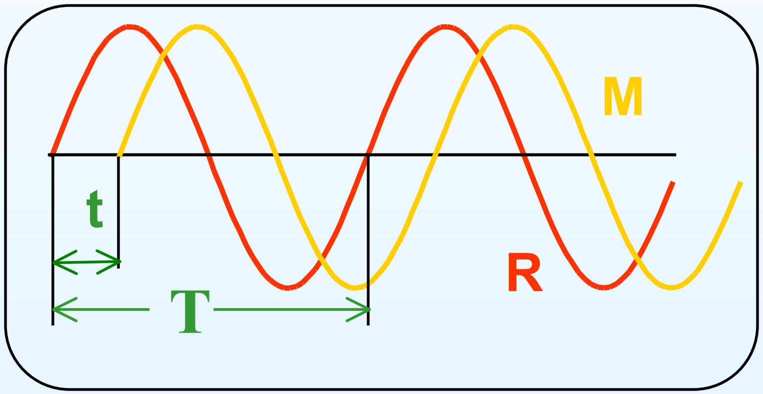


Phasemeter



Laser beam preparation bench

Stopwatch Phase Measurement System



- Aim
  - Verify performance of optical bench
  - Simple lab based system
- Want to measure phase of M relative to R
- Digitally count number of cycles of a fast clock during t and T, signal $\phi = 2\pi t/T$

- Potential noise sources
  - Quantisation noise can be sufficiently low (~10^{-6} cycles/√Hz, ie ~1pm /√Hz) with a fast clock frequency of ~100MHz and a heterodyne frequency of ~ 100kHz
  - Shot noise is irrelevant with the mW laser powers that are likely to be used
  - Care needs to be taken to keep phase changes in the analog electronics at a sufficiently low level

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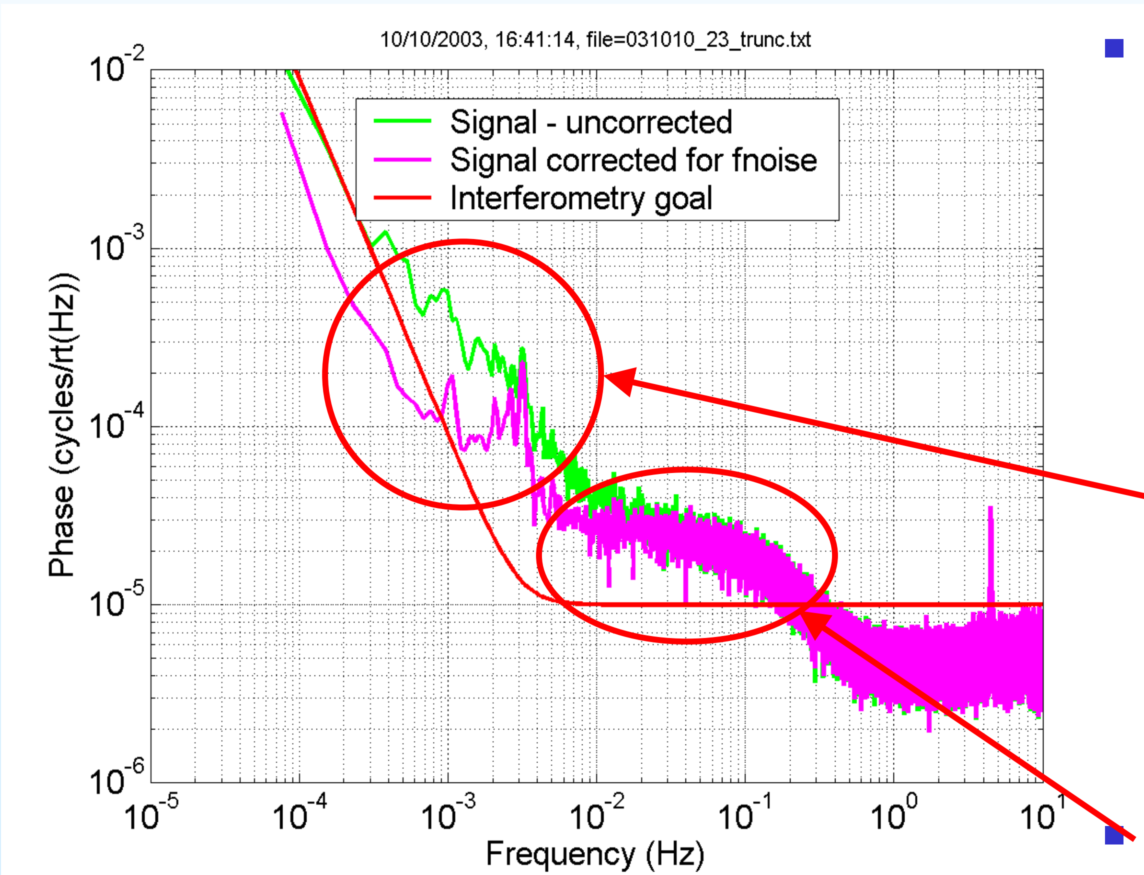
Early interferometer performance

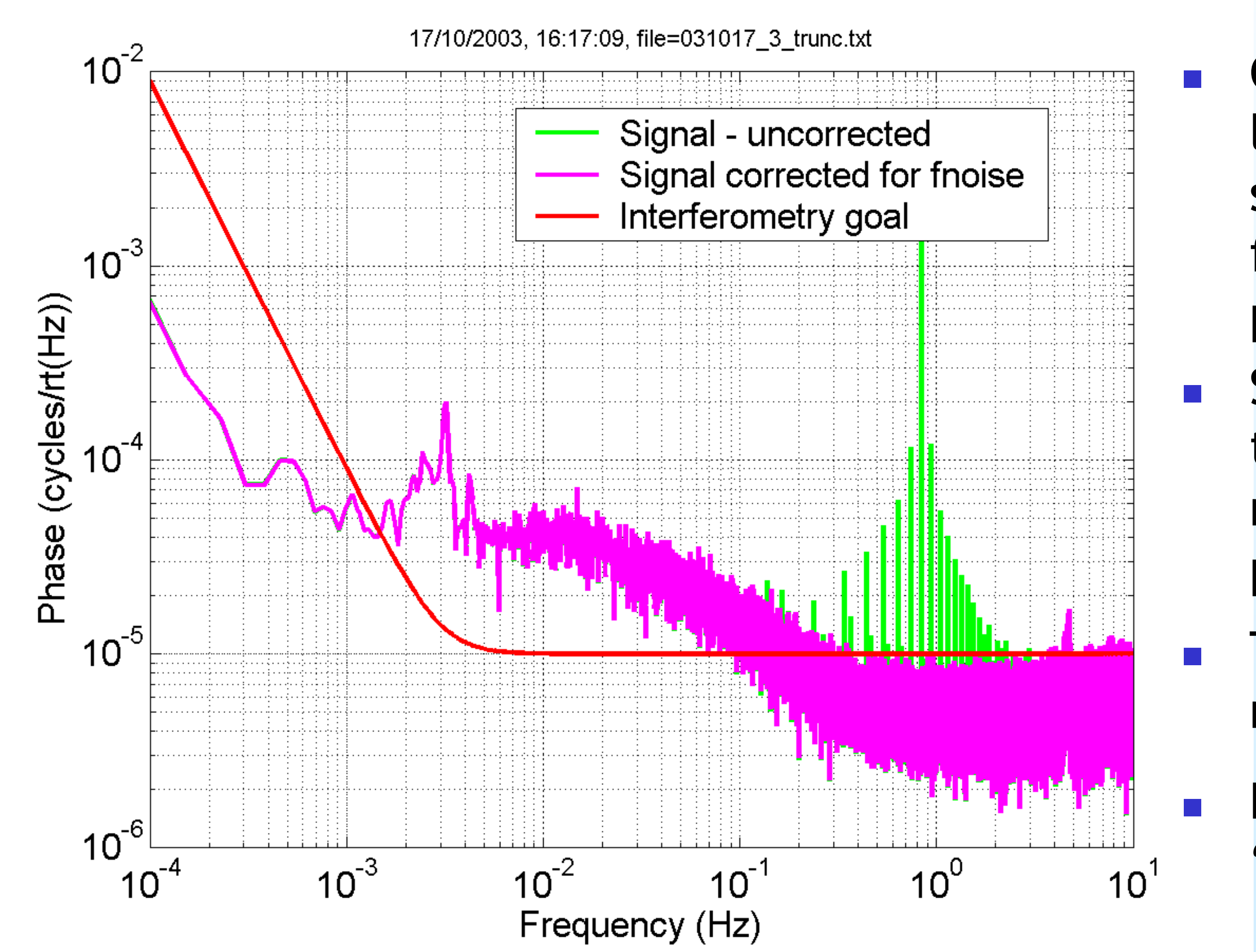


- Significant coupling of laser frequency noise
  - Coupling due to slight inequality of path lengths in the interferometer
  - Effect can be eliminated in post-processing or by laser frequency stabilisation
  - Some excess noise peaks remain around a few mHz
- Excess noise "plateau" at <100mHz

Laser frequency stabilisation

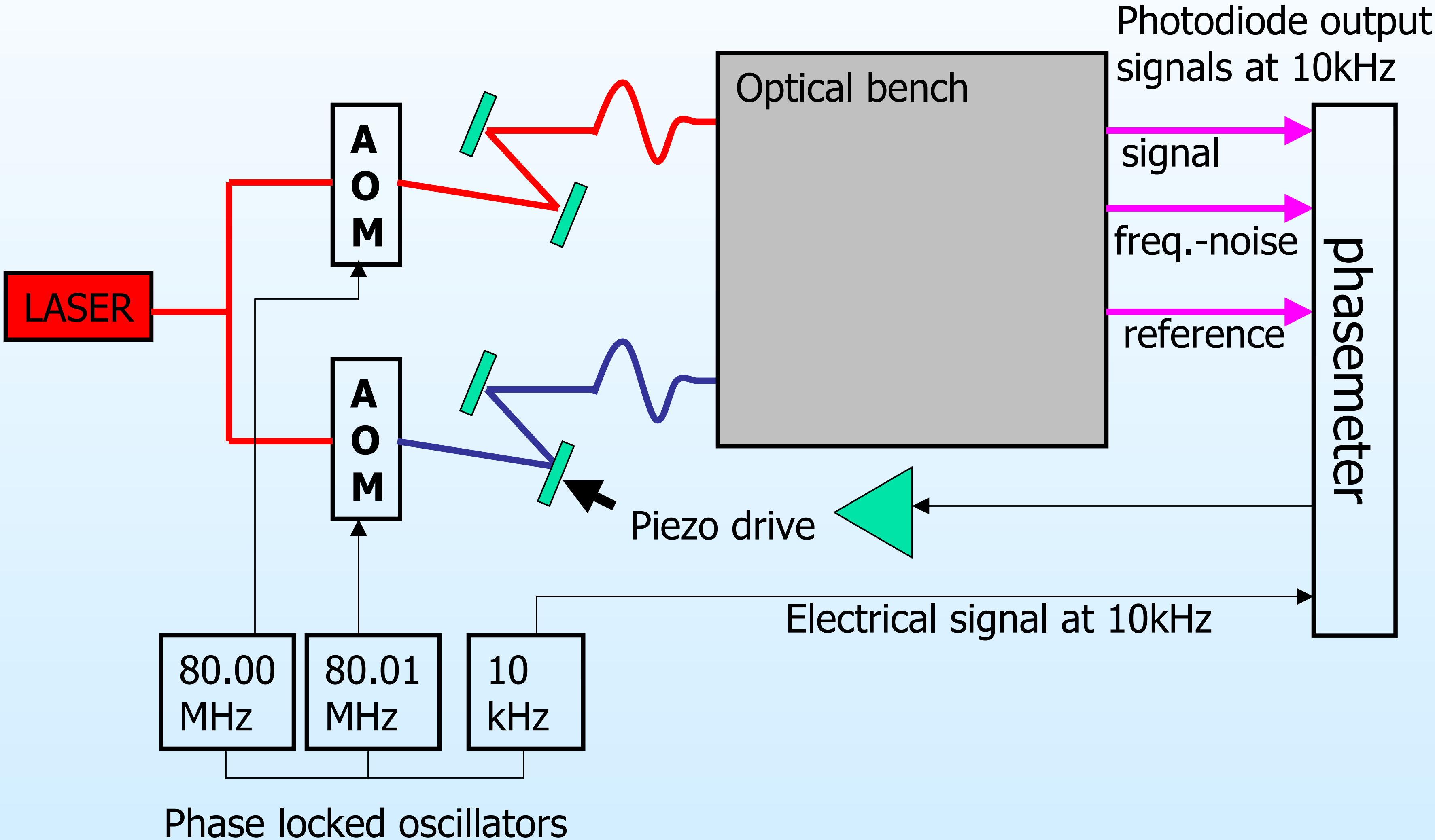
- Laser frequency noise significant at sensitivities close to LTP interferometry goal
  - Implement a laser frequency stabilisation control loop
- Sense using unequal arm length interferometer
  - Error signal from phasemeter (data rate 10 kHz)
    - Very simple logic on digital input signals to phasemeter produces output error signal (one inverter and 2 XOR gates)
  - Analog feedback to laser temperature and piezo on laser crystal
  - Frequency noise reduced by >100@1Hz
    - Reduces frequency noise to negligible levels at all measurement frequencies
  - Bandwidth few*100 Hz
    - Could be greater, but this is already sufficient

Performance with laser frequency stabilisation



- Green trace is with laser frequency stabilised but with a frequency modulation peak at 0.9 Hz
- Similar performance to laser frequency noise subtraction in post processing
- Temperature driven noise at 3mHz?
- Excess noise "plateau" at <100mHz

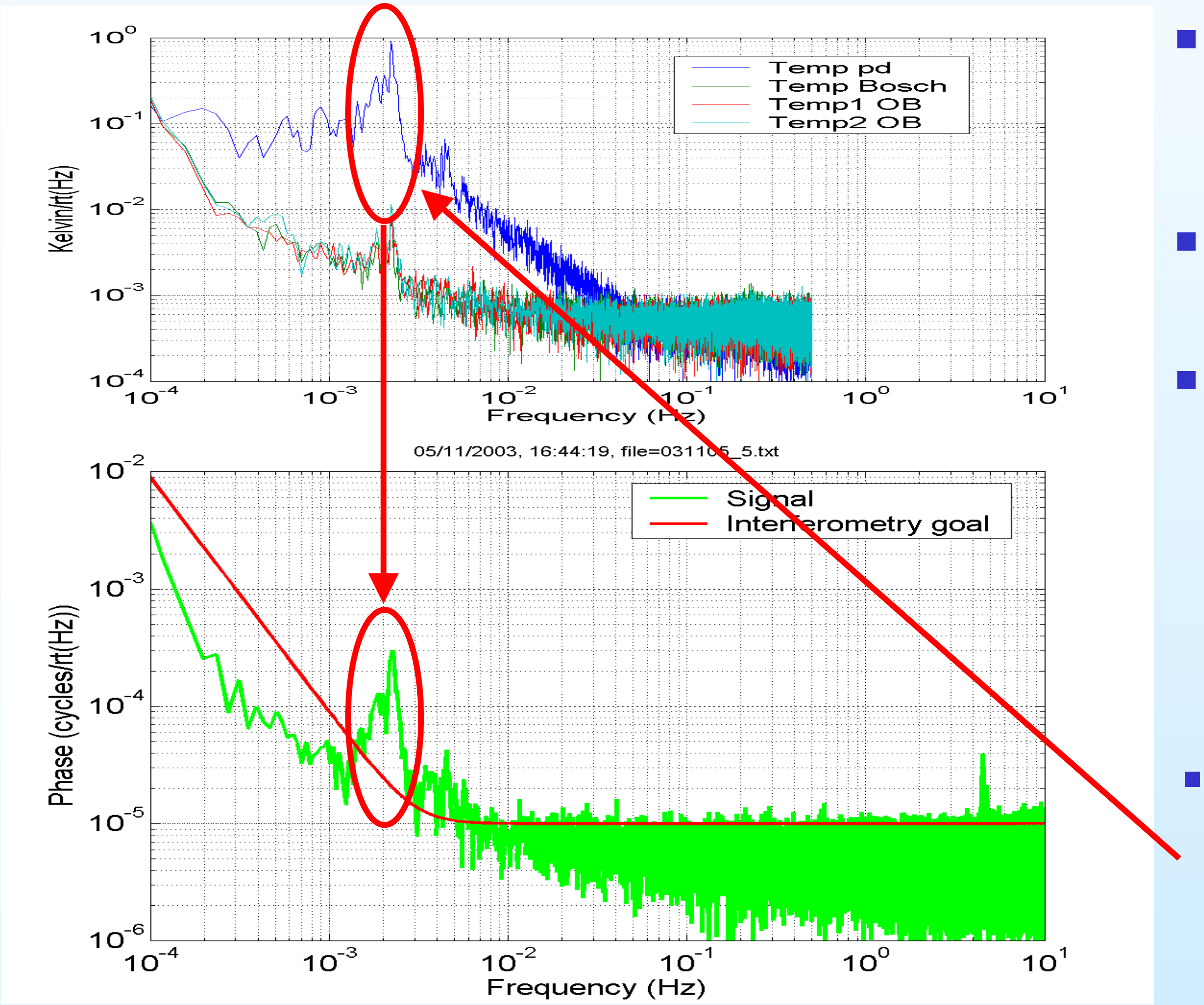
Optical and electrical heterodyne signals



Stabilise phase of reference heterodyne

- Sense phase difference between electrical heterodyne and optical heterodyne
  - Electrical heterodyne into another phasemeter channel
  - Error signal from phasemeter (data rate 10 kHz)
    - Same simple logic as for frequency stabilisation
- Stabilise optical heterodyne phase by feeding back to piezo driven mirror directing light into one optical fibre
  - Loop bandwidth 10Hz
    - Probably limited by mechanical resonance
  - Residual fluctuations $<\pm 20$ degrees

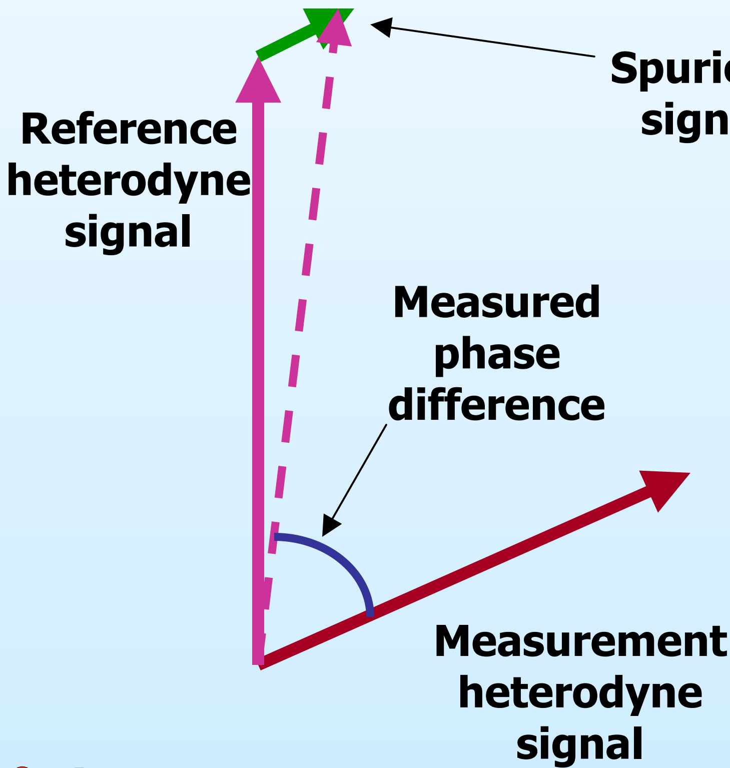
Results with fibre path stabilisation

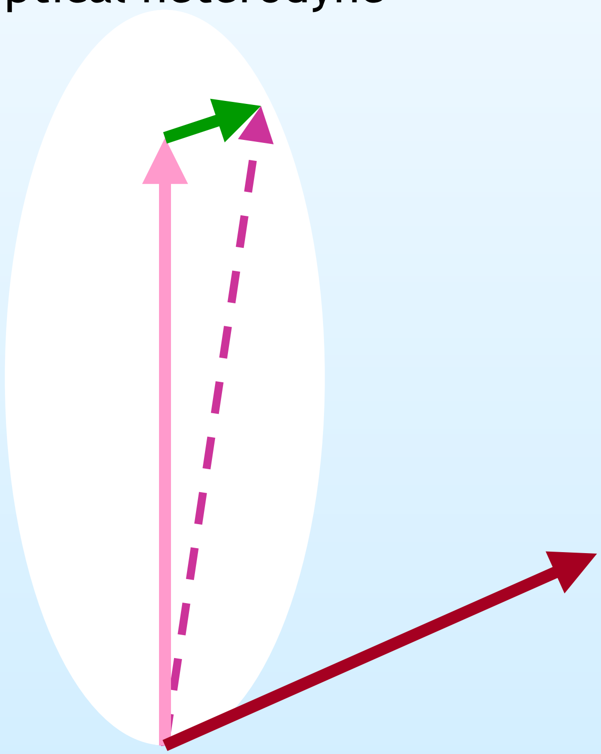


- Differential fibre path lengths stabilised
- Laser frequency stabilised
- Meets LTP interferometry goal over almost complete measurement band
- Temperature driven noise around few mHz

Why does stabilising the reference optical heterodyne to the source oscillator make a difference?

- Generation of spurious signals on the outputs of the photodetectors
  - at the heterodyne frequency
  - phase locked to the source oscillator
  - Unstable with respect to the optical heterodyne





Excess noise coupling

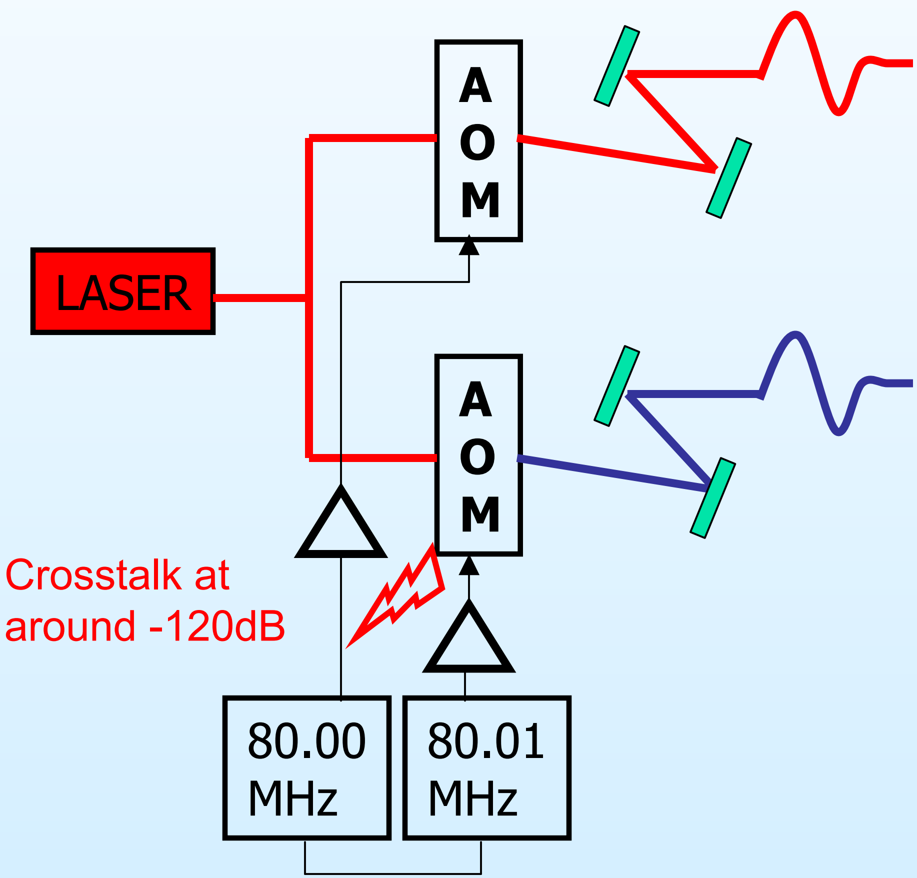
- Excess noise at <0.1 Hz caused by a combination of:
  - Spurious signal at the heterodyne frequency
  - Changing relative phase of optical and electrical heterodynes (“fibre” noise)

Possible causes of spurious signal-1

- Direct electrical interference into photodiode front ends at the heterodyne frequency (10 kHz)
  - Excluded after investigation

- Amplitude modulation of the diffracted light observed at the 80MHz rf frequency and multiples thereof, typically ~10^{-3}
  - In principle these signals should not produce 10kHz beat signals but undesired nonlinearities in the photodiode front end may allow the generation of a 10kHz beat
  - Such additional beats only present when the beams are recombined and are therefore invisible, being masked by the much larger heterodyne signal

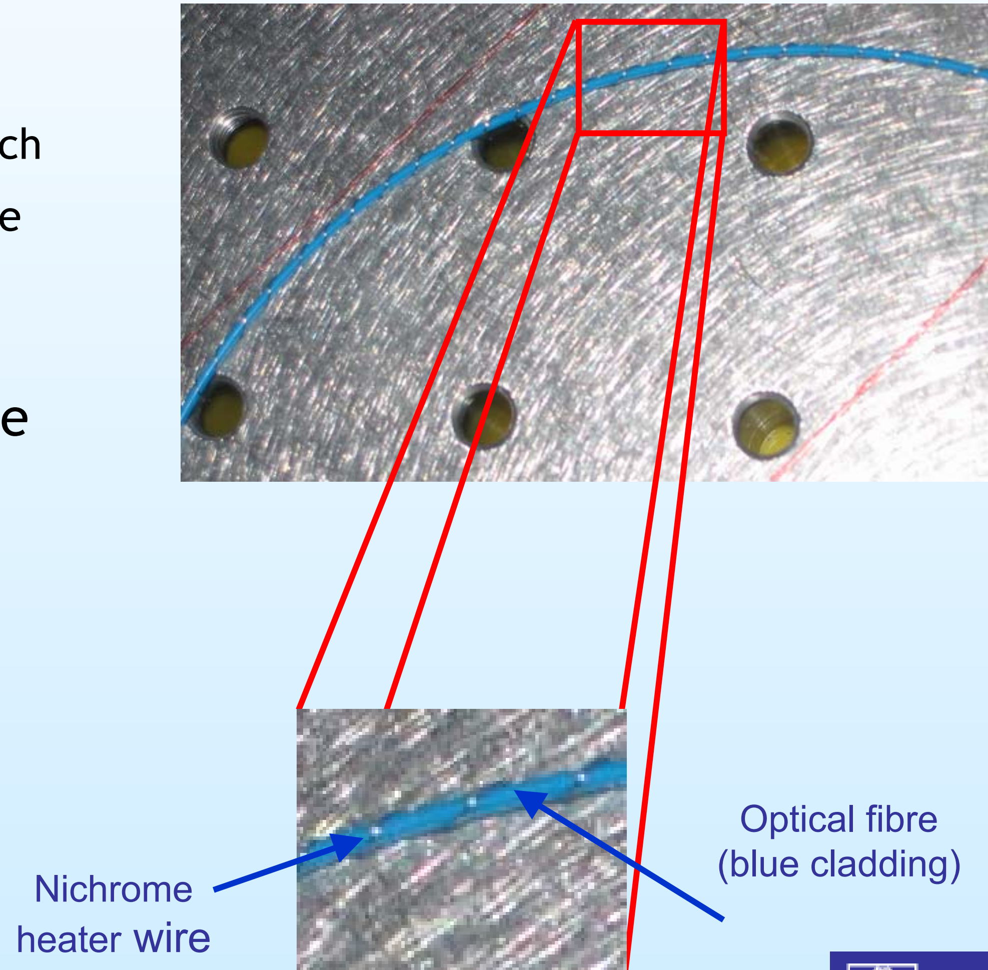
Possible causes of spurious signal-2



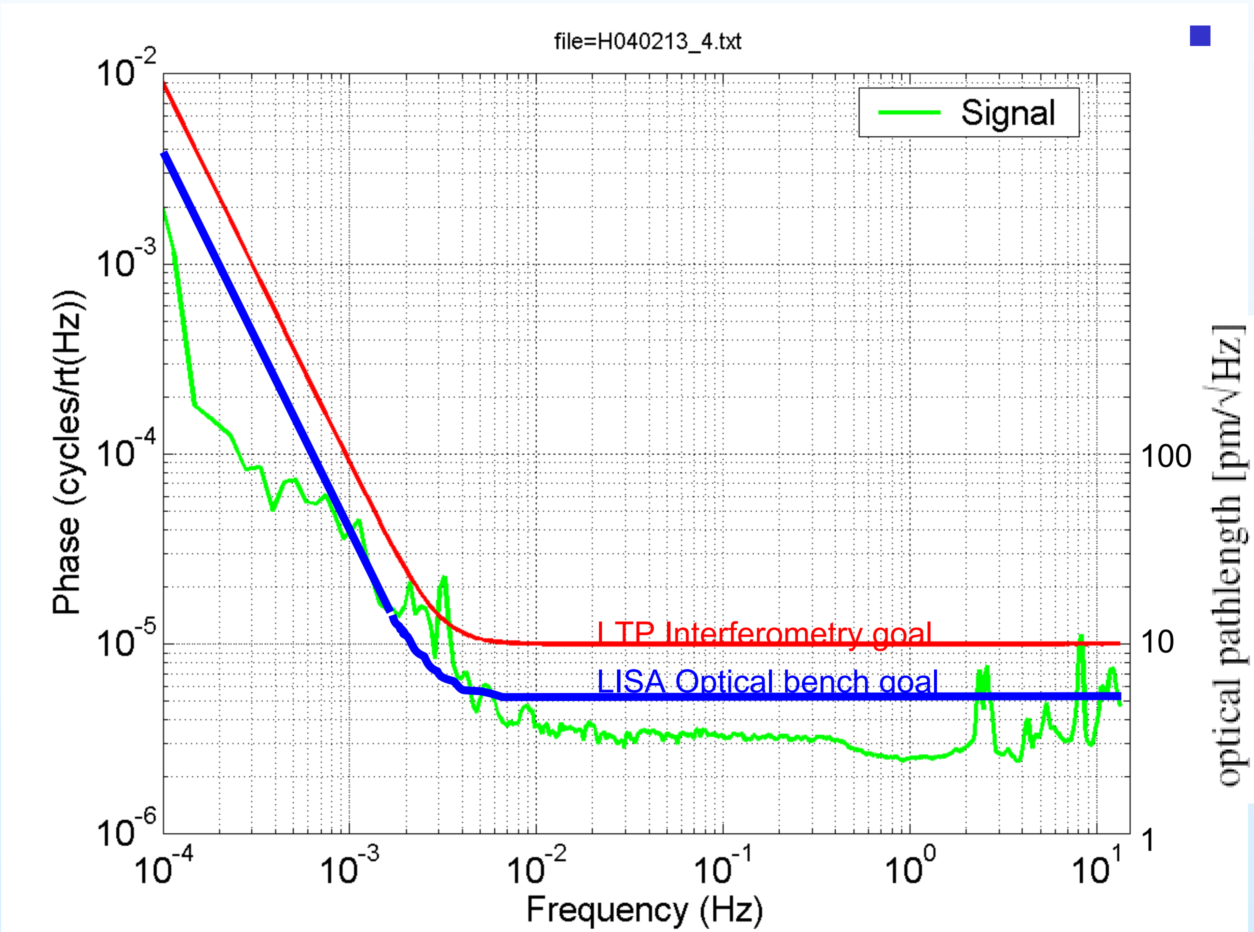
- Electrical cross talk of *rf* signals resulting in each AOM being driven by a small amount of the *rf* signal intended for the other AOM
  - Observed as a 10kHz beat in light from a single AOM
    - ~90dB below main heterodyne signal size
  - Does not seem to be straightforward to further reduce this coupling significantly in our experimental configuration

Differential fibre-path stabilisation

- First attempt
  - PZT driven mirror on beam preparation bench
  - Works, but not suitable for LTP
- Second approach - fibre heating
  - Resistance wire wrapped round fibres
  - Works with lower bandwidth (4 Hz)
  - Currently adopted solution for LTP



Results

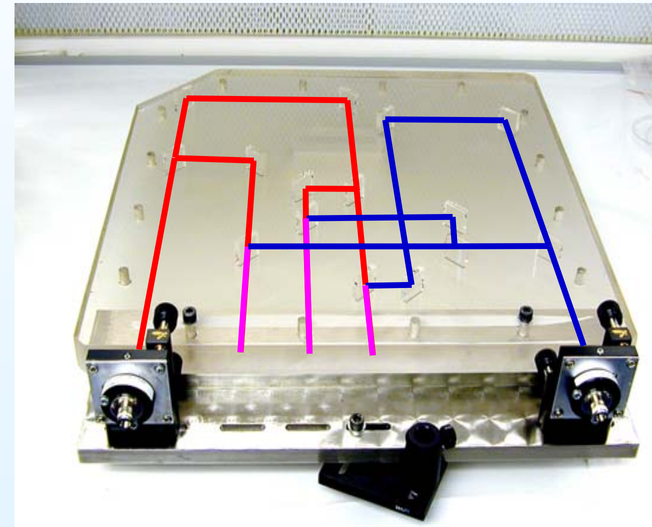


Performance measured using Hannover phasemeter

- Meets LTP and LISA stability goals over the whole frequency range…
  - …apart from some excess noise around few mHz
  - Temperature driven effects
    - Consistent with expected effects in transmissive optics
    - Bench stability in lab. ~mK/rt(Hz)
    - LISA stability μk/rt(Hz)

Conclusions

- Prototype optical bench built
  - Lessons learned for EM build
  - (See posters on LPF EM Optical Bench)
- Optical bench stability
  - LTP and LISA
- LTP interferometry demonstrated
  - Laser frequency stabilisation
  - Unexpected noise source identified
  - Amelioration strategy demonstrated
    - Fibre path feedback
    - Necessary for performance demonstration on EM
  - LTP compatible feedback demonstrated
    - Temperature feedback



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