Phase locking for LISA

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Talk outline

- The need for weak light phase locking in LISA
- An arrangement for demonstrating weak light phase locking in the laboratory
- Subsystems of the experiment
- Current status

LISA light levels

- Each spacecraft houses two phase locked lasers which each emit beams to the other two spacecraft
- The beams start off collimated with diameter 40cm
- Upon arrival at the receiving spacecraft ($5*10^9$m away) the beam has expanded to diameter of order 20km, resulting in only a small amount of the transmitted beam being detected
- LISA light levels will be of order 1W transmitted and ~300pW received
  - *This attenuation means that the receiving spacecraft cannot simply reflect the light*

Weak light phase measurement

- Doppler shifts in LISA can change the frequency of the beatnote between two lasers by up to 15MHz
- For LISA to operate we have to be able to measure the phase of the received light until we are limited only by shot noise

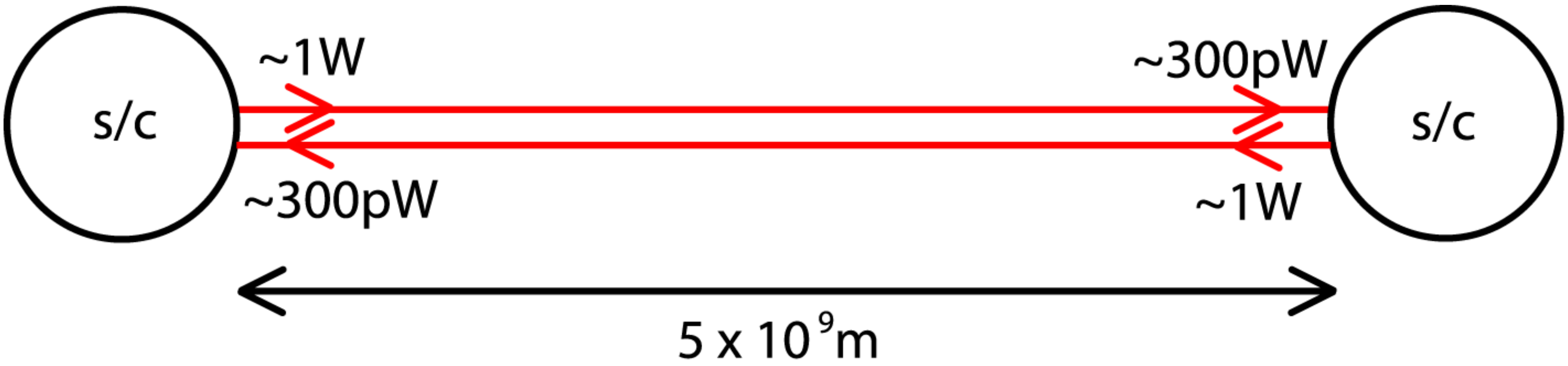


Figure 1: Simplified LISA layout for two spacecraft

Situation at each spacecraft

- One possible mode of operation is to hard lock the 'reflected' light to the incoming weak beam

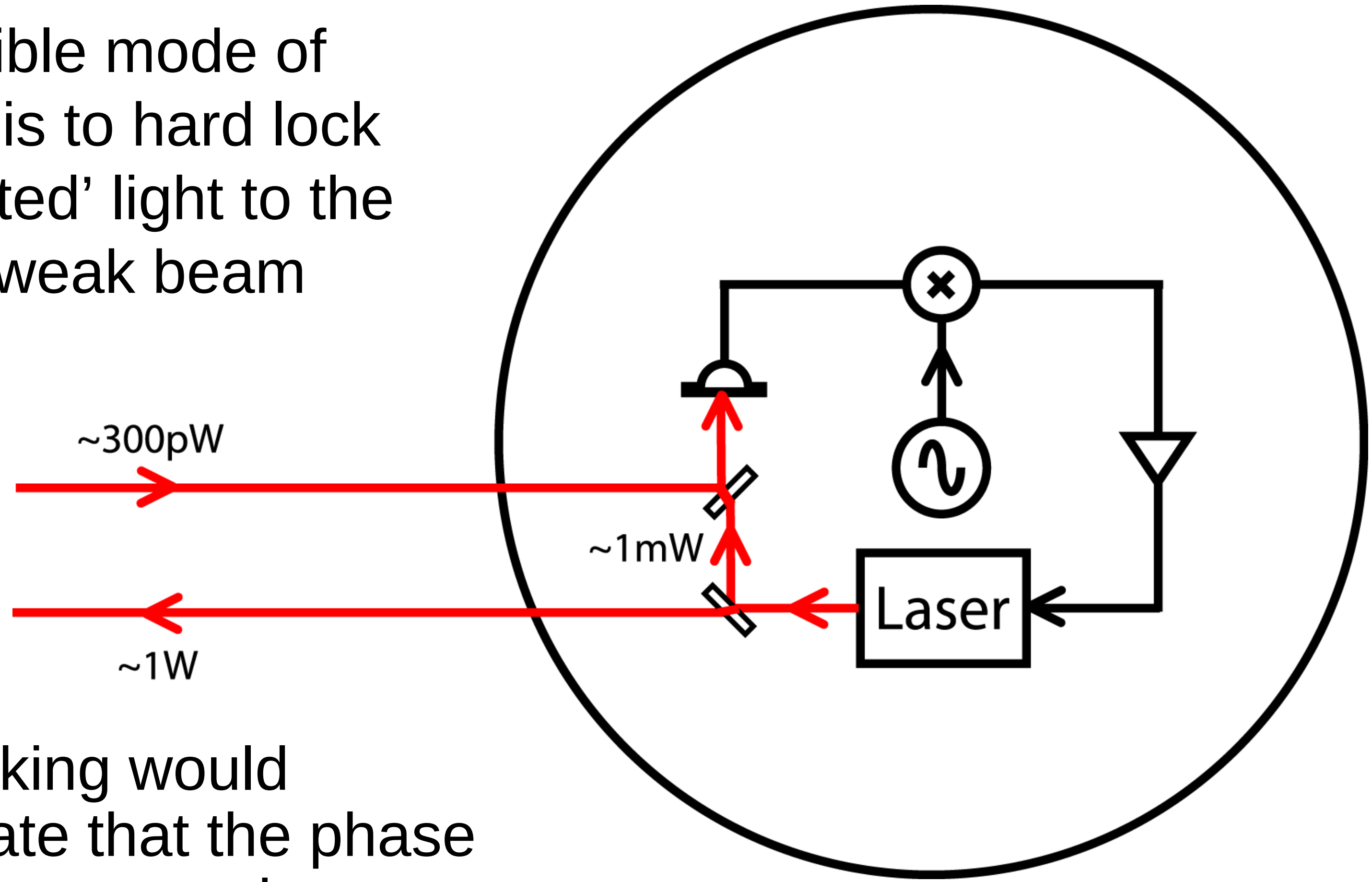


Figure 2: Single spacecraft

- Phase locking would demonstrate that the phase has been measured to required accuracy

Lab demonstration (1)

- We aim to demonstrate phase locking at LISA power levels in a lab experiment

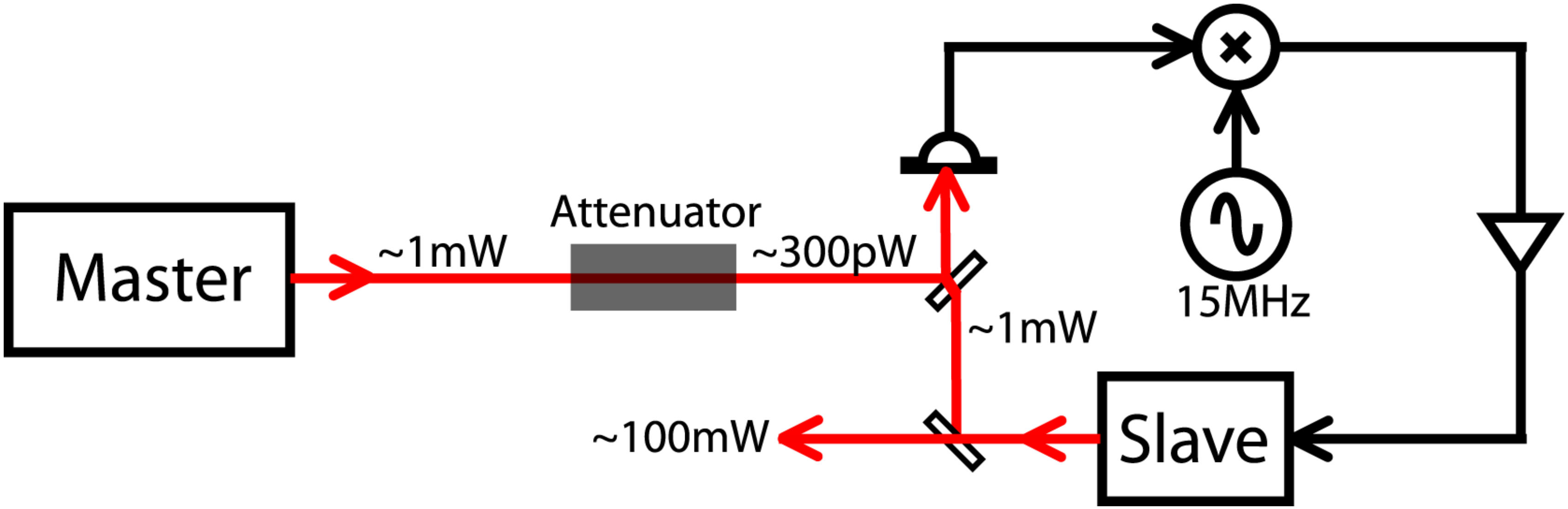


Figure 3: Phase locking to weak light

Lab demonstration (2)

- High power interference gives us phase measurement where shot noise is a factor of ~1000 lower
- All oscillators are phase locked together

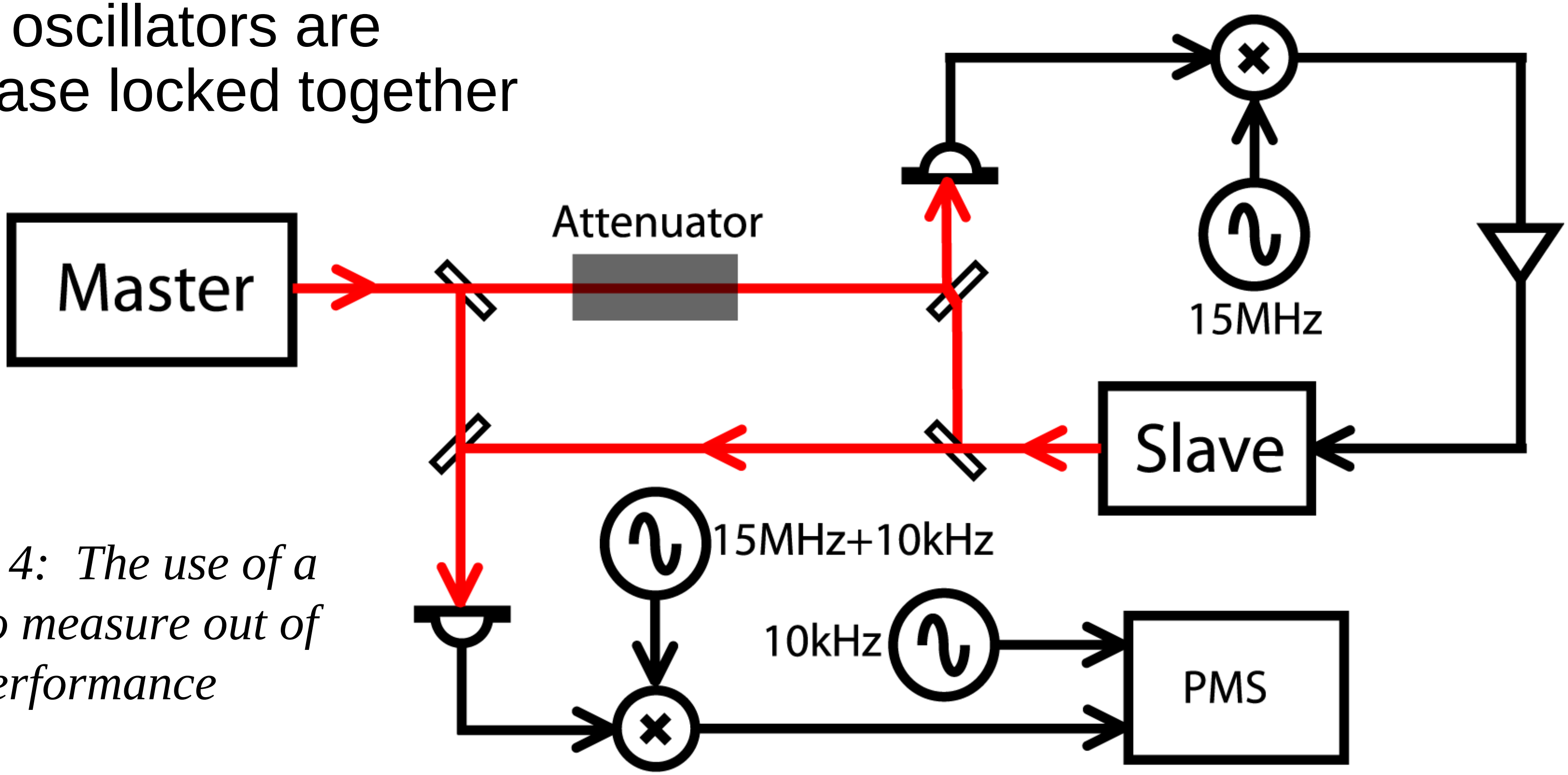


Figure 4: The use of a PMS to measure out of loop performance

Lab demonstration (3)

- An output of PMS can be used for LF feedback
- This could help avoid mixer flicker noise

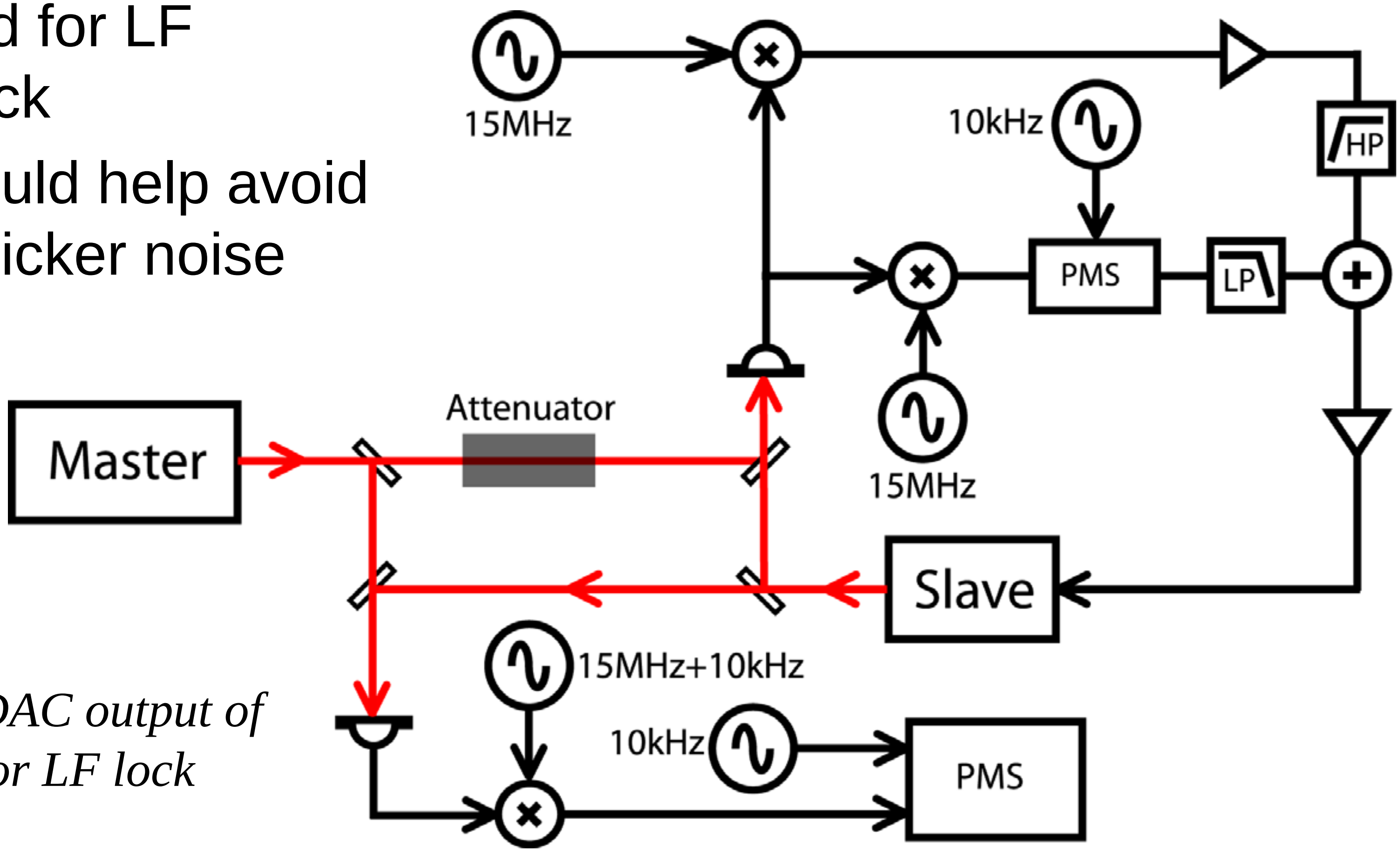


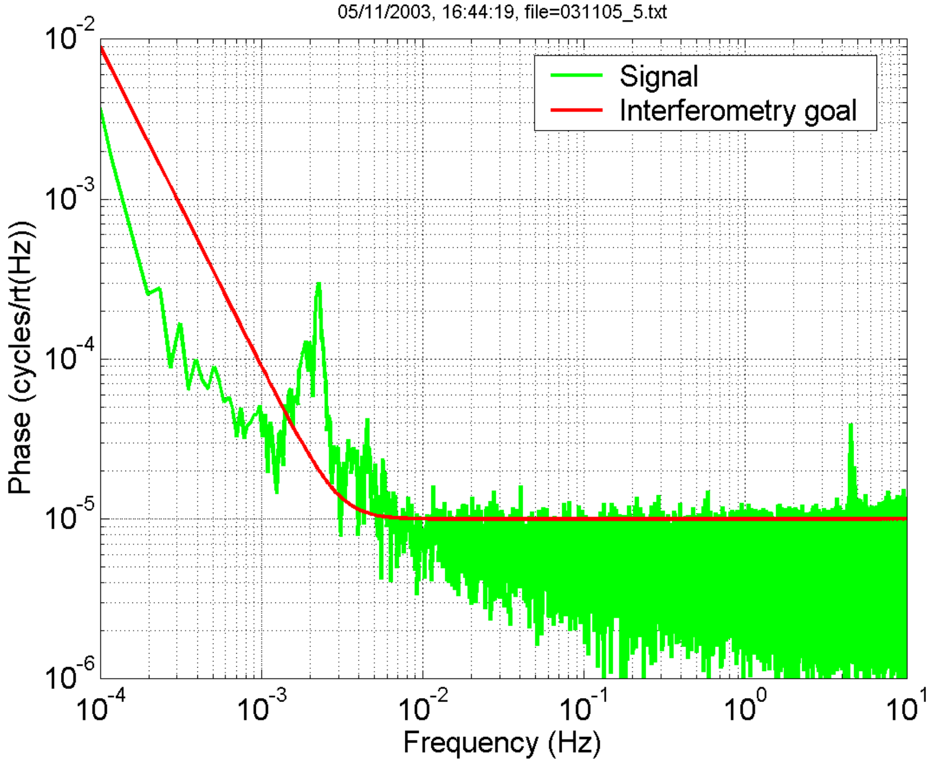
Figure 5: DAC output of PMS used for LF lock

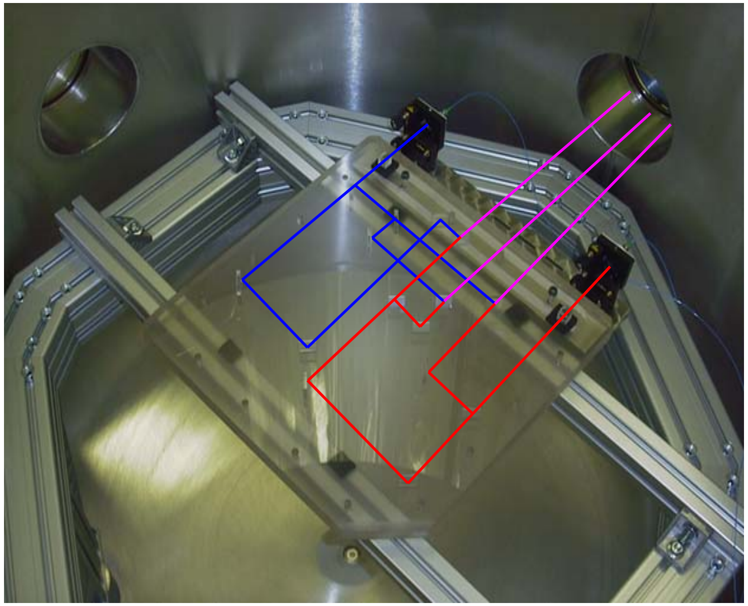
Preliminary investigations

- The experiment must be built up from components that are stable enough when combined to reach the overall goal
- A series of sequential experiments have been conducted to ensure this:
  - Stable interferometer and phase measurement system demonstrated
  - Phase locked oscillators through comparators into phase meter
  - Phase locked oscillators via mixers and comparators into phase meter
  - Optical signals (via front ends) locked to oscillators, through comparators and into phase meter

Optical bench stability

- Well characterised optical bench
- Intrinsic stability of system (including PMS) good enough to realise goal

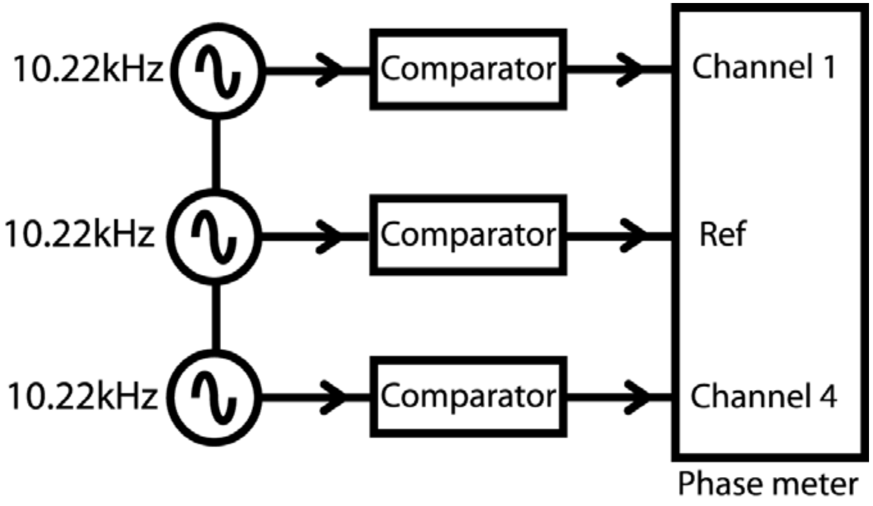


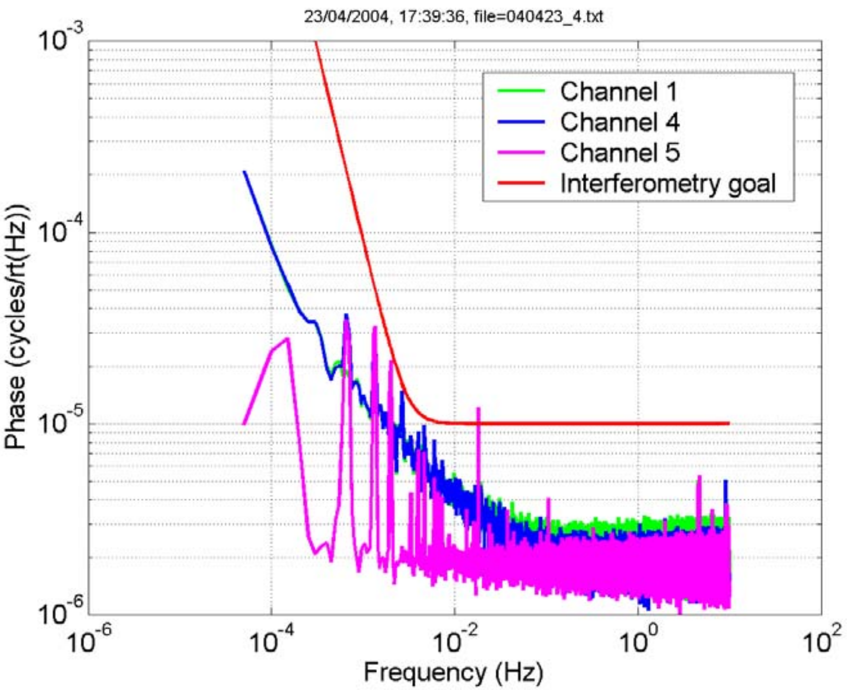


- Slight excess noise in the 1.5 to 5mHz region is due to environmental temperature fluctuations
- Servos operating to stabilise laser frequency and differential length fluctuations in the fibre feed paths

Oscillator test

- Initial test: that phase locked oscillators and PMS noise floor is sufficiently low
- PMS channel 5 is the difference between phase in channels 1 and 4

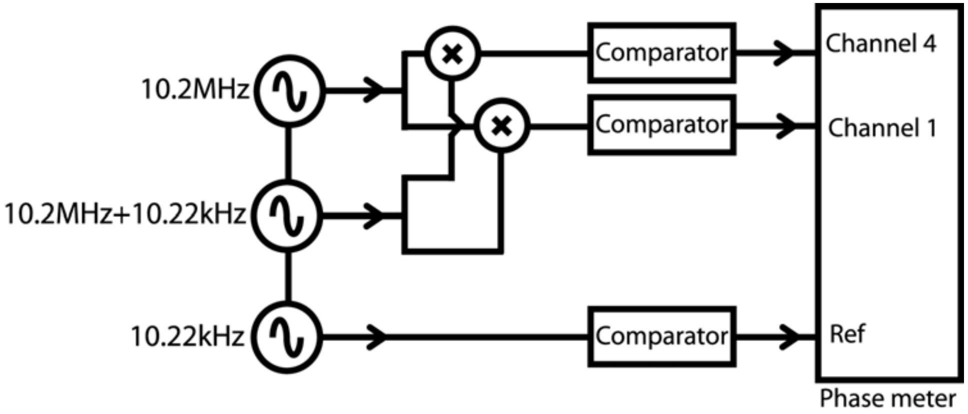


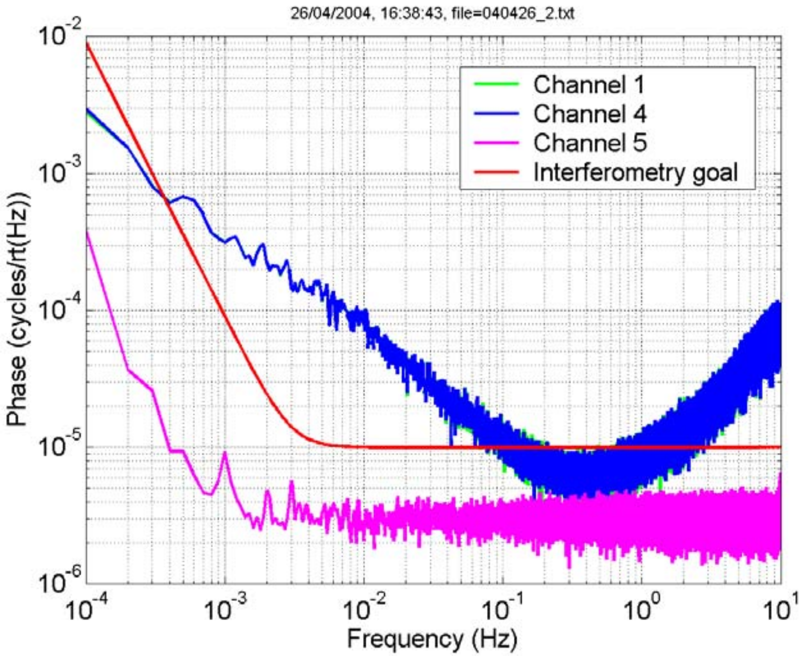


- Red curve shows LPF interferometry target

Mixer test

- Now introduce mixers to the chain
- One of the comparators is noisy, showing up as common mode noise

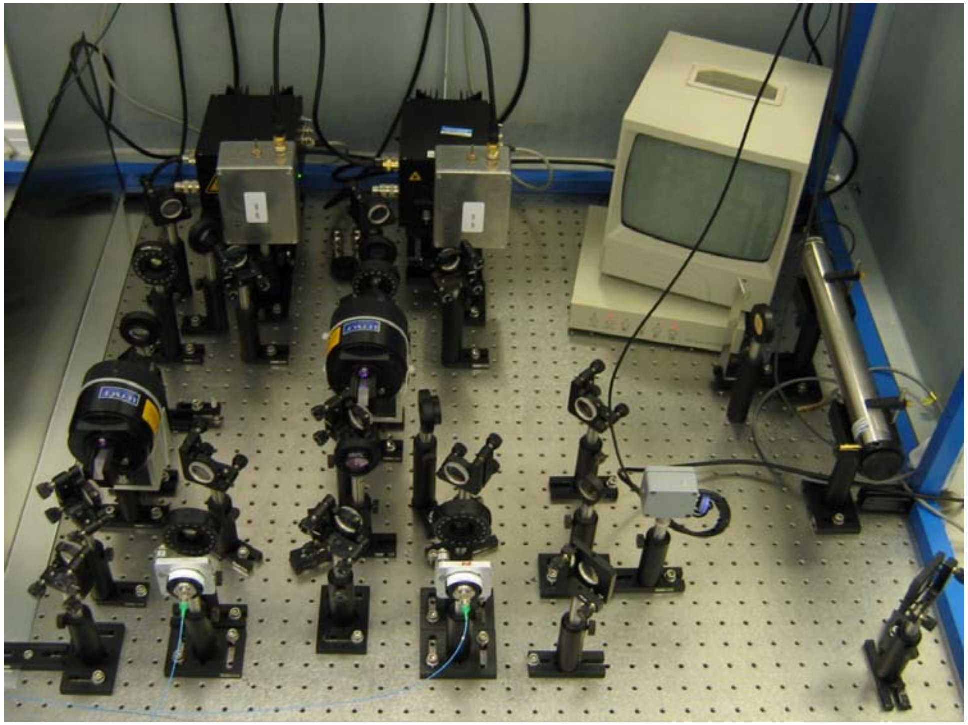




- Satisfactory noise floor

Optical signals

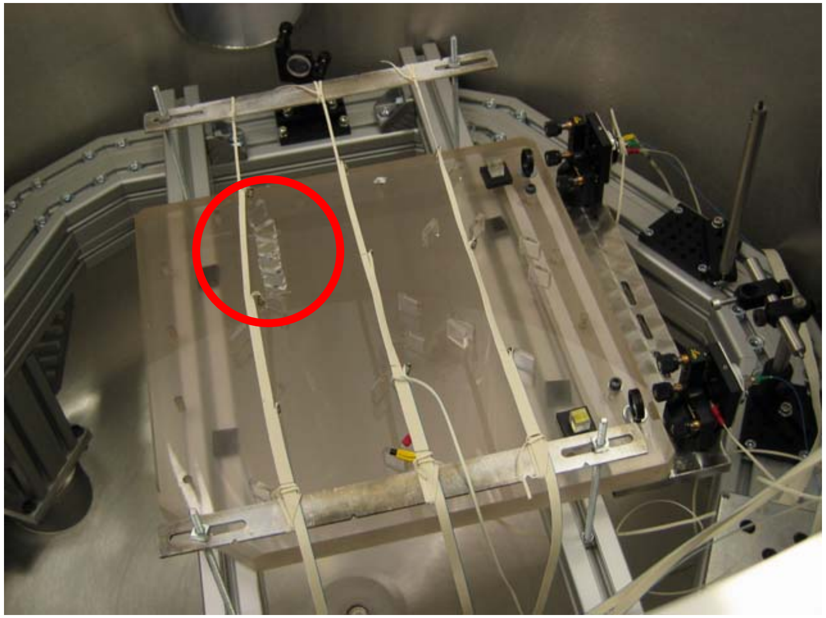
- The optical signals are generated by two NPRO Nd:YAG lasers
- The lasers are fibre coupled onto an ultra-stable optical bench in an evacuated tank

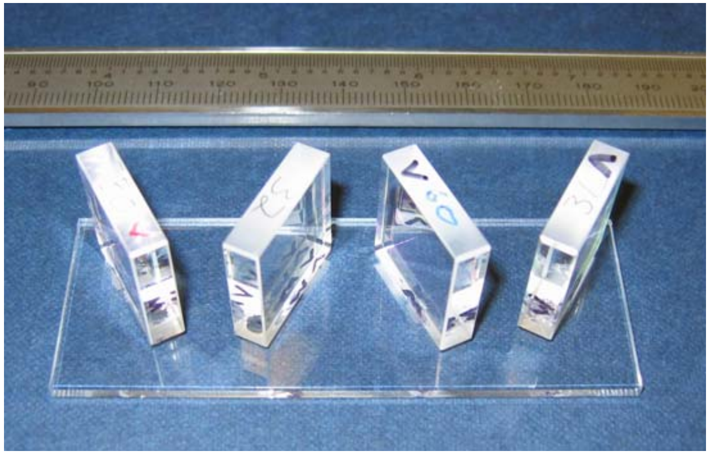


- The beams are combined at three interference points, which are directed onto the front ends (photodiodes with preamplifiers) outside the tank

Attenuation

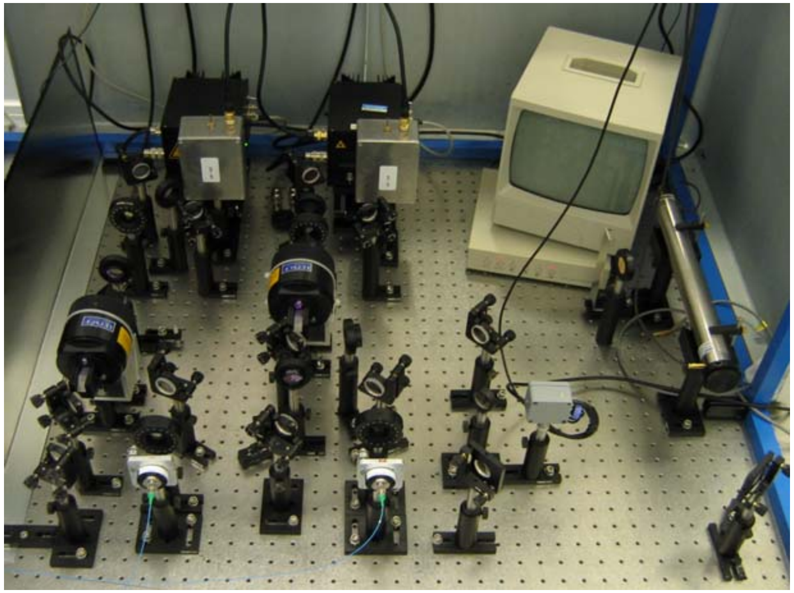
- Optical bench originally designed to be operated with equal power in each arm
- Power in one arm of one interference attenuated
- Unwanted light is reflected out of the optical system by four mirrors angled to the beam
- Attenuation of $\sim 6*10^6$ is achieved, giving weak light power of ~320pW from ~2mW

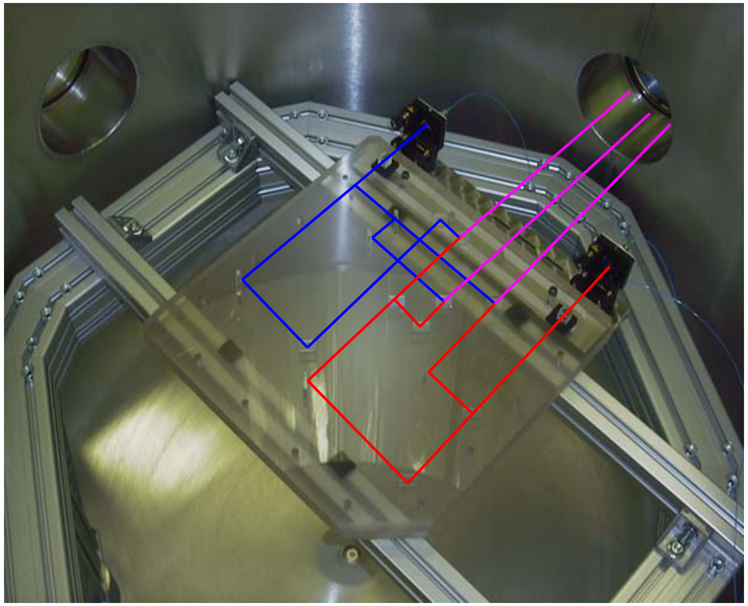




Current status

- Ultra-stable interferometer verified
- Laser bench complete
- Phase locking demonstrated with offset frequencies ~3-30MHz
- Light attenuation in place





- Work to be done:
  - Lock on weak light
  - Frequency noise stabilisation
  - Digital feedback for LF lock