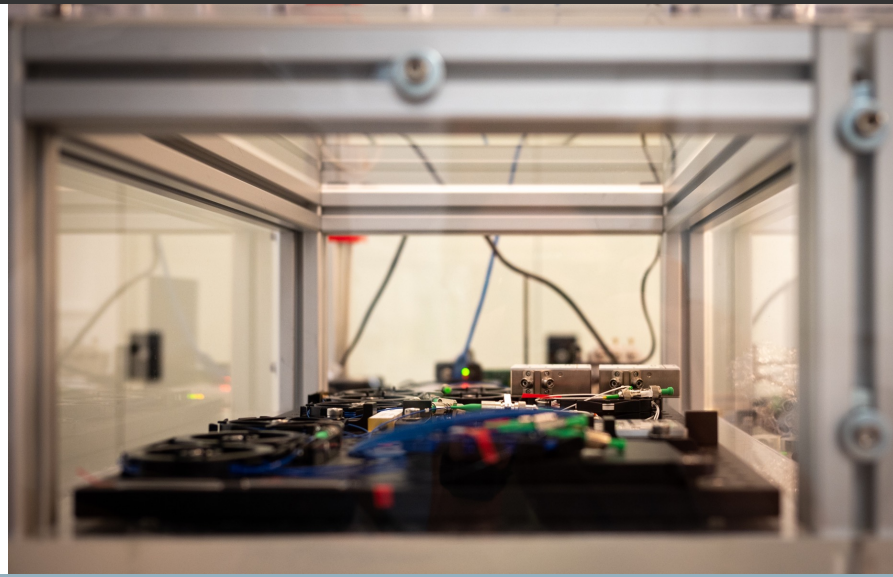
Australian National University

Digital Interferometry for Suspension Platform Interferometer



ANU CENTRE FOR GRAVITATIONAL ASTROPHYSICS

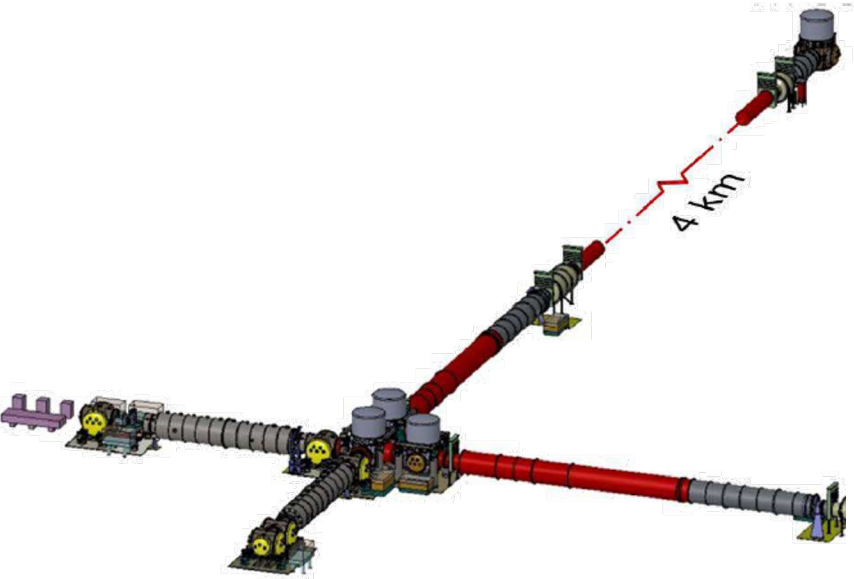
OzGrav

Ya Zhang, Sheon Chua, Bram Slagmolen

With help from: Paul Sibley, Chathura Bandutunga, Kirk McKenzie

Centre for Gravitational Astrophysics
Research Schools of Physics, and of Astronomy and Astrophysics
ARC Centre of Excellence for Gravitational Wave Discovery
The Australian National University

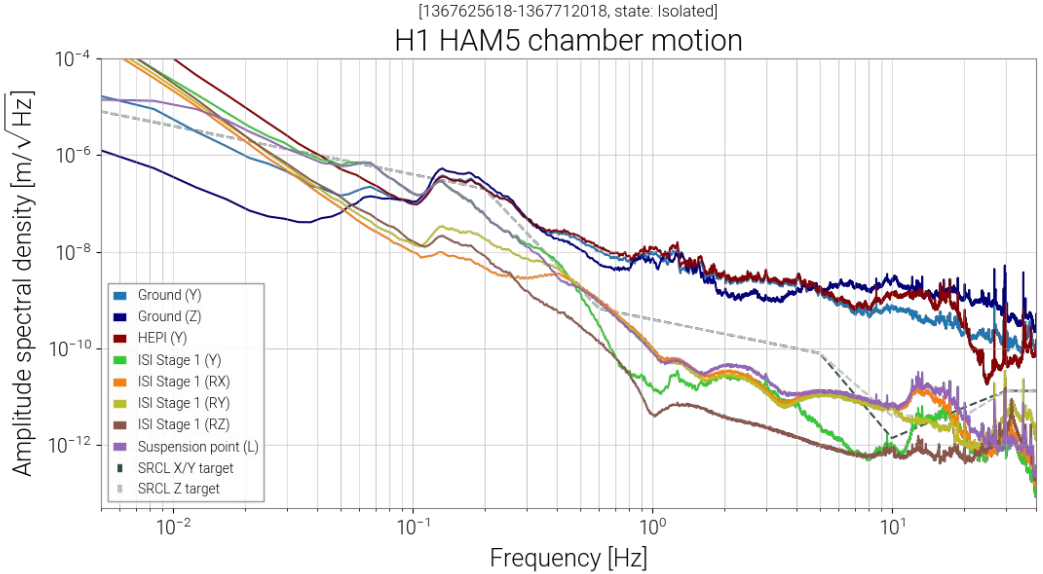
LIGO's Seismic Achievements an Challenges



Concerned with seismic motion in the context of GW detection

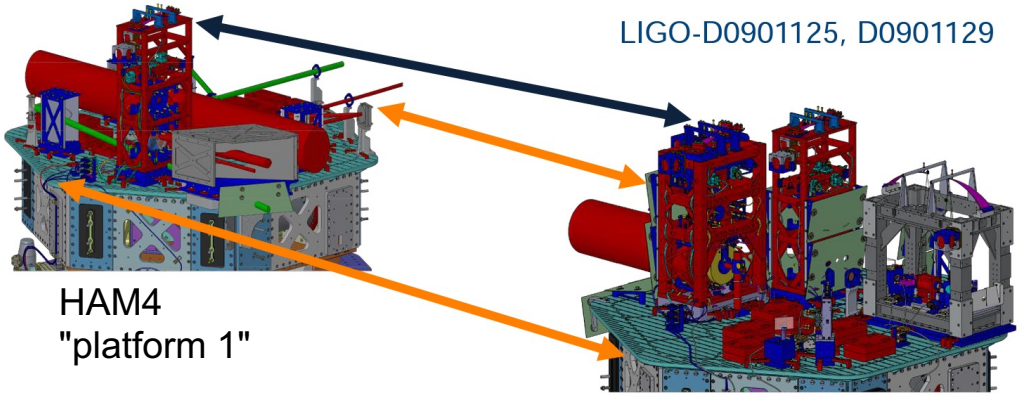
LIGO has 11 seismic isolation platforms (BSC & HAM)

Suspension platform interferometer (SPI) helps control differential motion < 1Hz



D. E. Clark, "Control of differential motion between adjacent advanced LIGO seismic isolation platforms", PhD thesis, 2013.

Suspension Platform Interferometer (SPI)



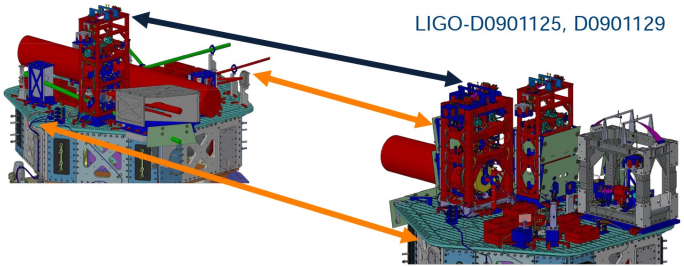
Optical interferometry ↔ optical sensitivity

Efforts at Uni Tokyo, AEI and Stanford

Vacuum and convenience of operation call for optically simple setup

- Active vibration isolation using a Suspension Point Interferometer (Y Aso, M Ando, S Otsuka and K Tsubono, *2006*, DOI 10.1088/1742-6596/32/1/069)
- Towards a Suspension Platform Interferometer for the AEI 10 m Prototype Interferometer (K Dahl, A Bertolini, M Born, Y Chen, et al, *2010*, DOI 10.1088/1742-6596/228/1/012027)
- A study on motion reduction for suspended platforms used in gravitational wave detectors (S Koehlenbeck, C Mow-Lowry, G Bergmann, R Kirchoff, et al, *2023*, DOI 10.1038/s41598-023-29418-x)

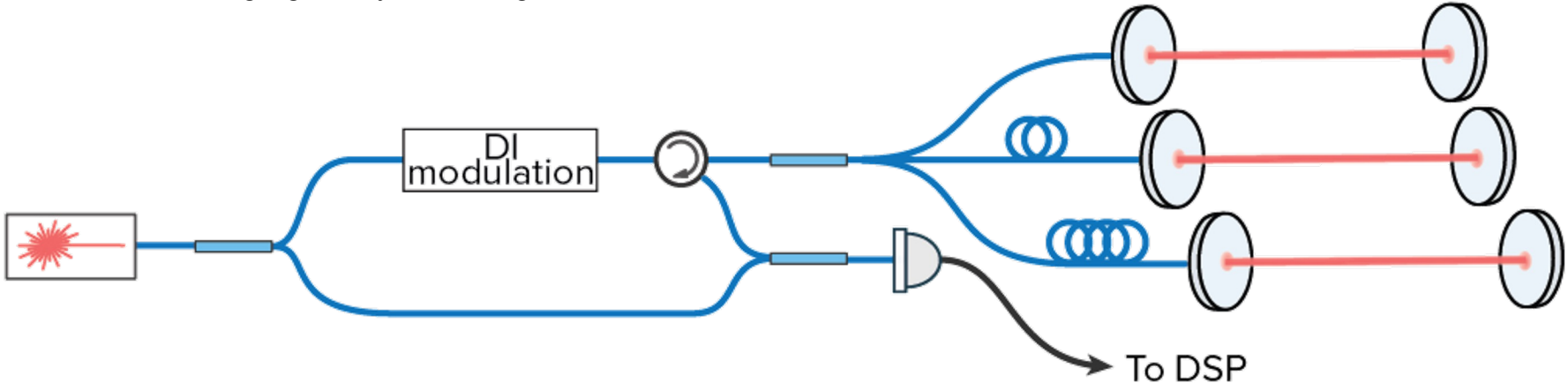
Suspension Platform Interferometer (SPI)



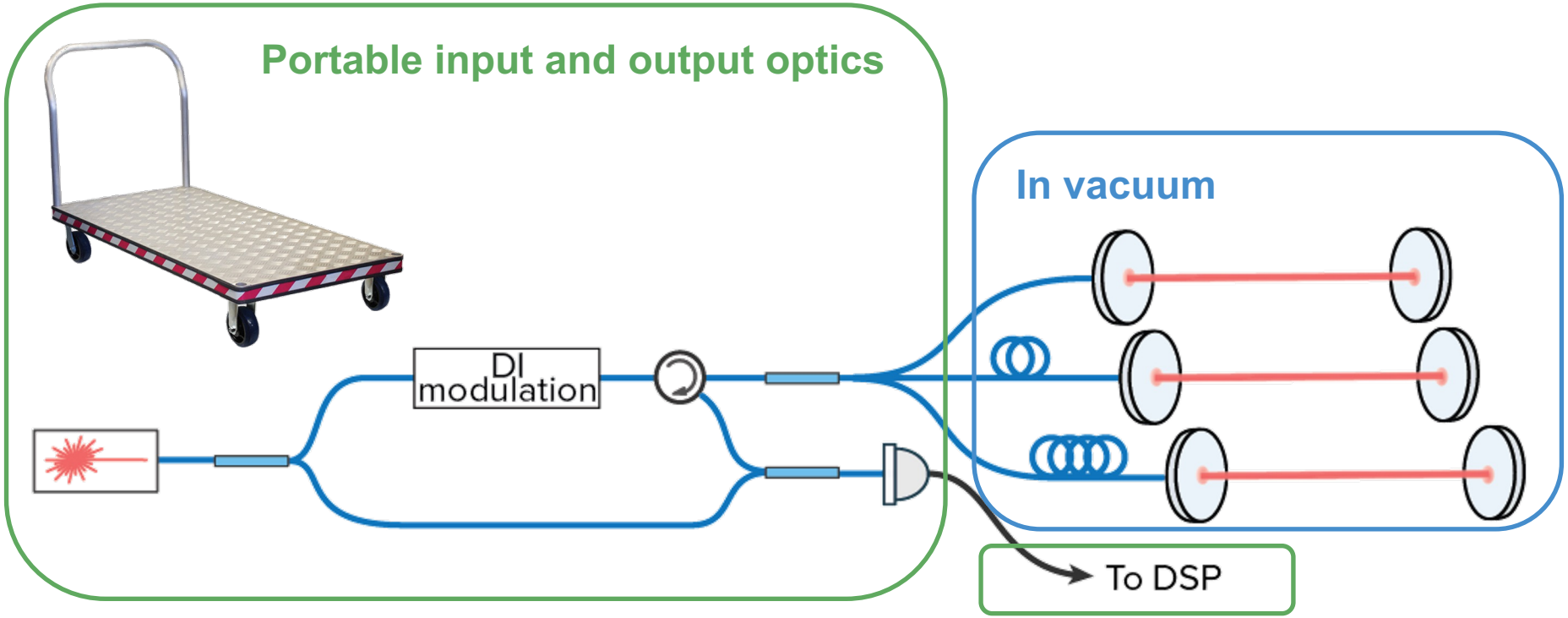
Michelson interferometer

Multiplexing using digital interferometry (DI)

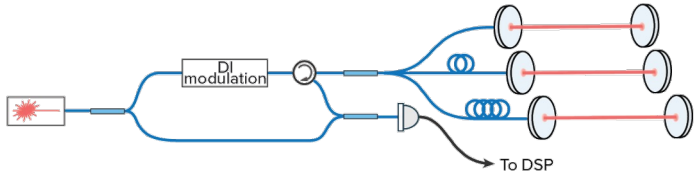
DI – differentiating signals by time-of-flight

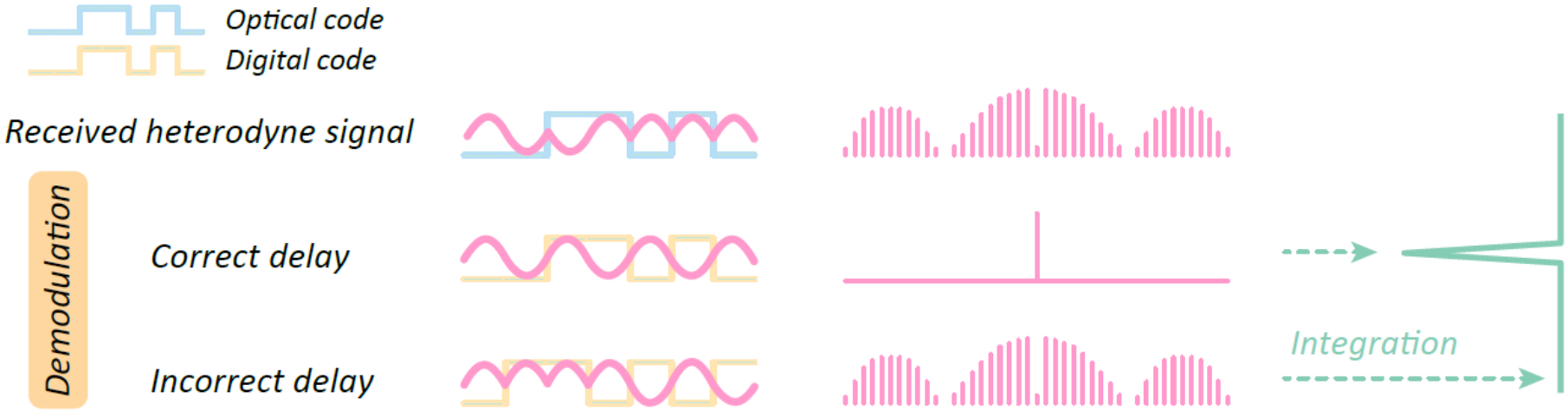


Suspension Platform Interferometer (SPI)



Multiplexing – Digital Interferometry





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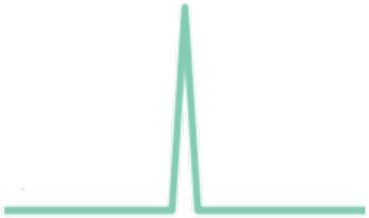
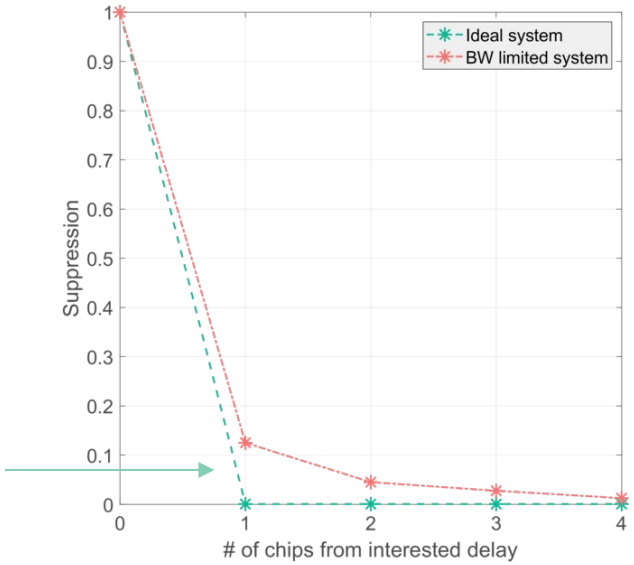


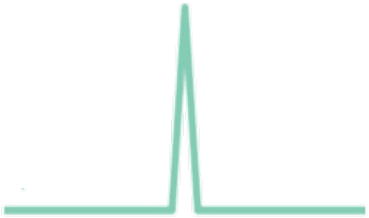
Ideal Correlation



- DI requires us to capture broadband spectral information
- Electronic systems have bandwidth limitations
- This leads to compromised auto-correlation performance

Solution: increase separation (i.e. physical distance) of individual demodulation channels.

Multiplexing – Digital Interferometry



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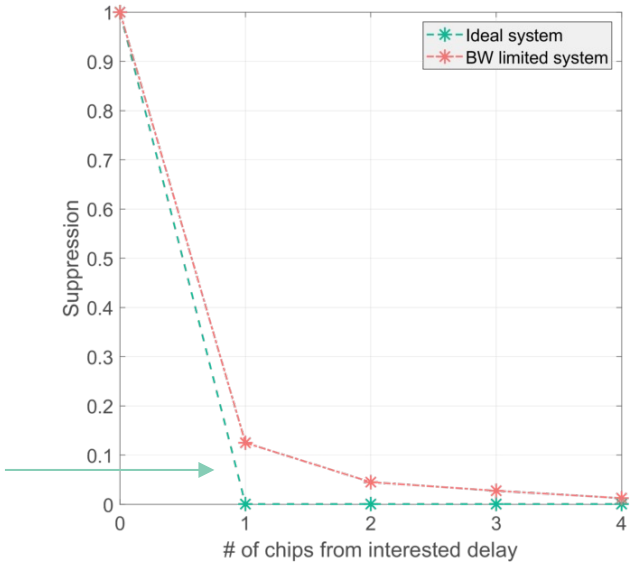

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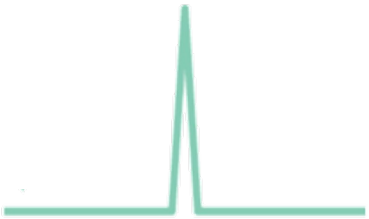
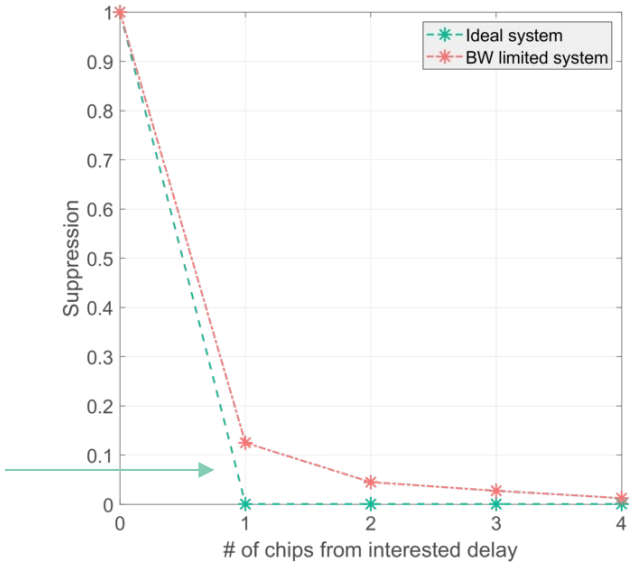
Multiplexing – Digital Interferometry



Ideal Correlation



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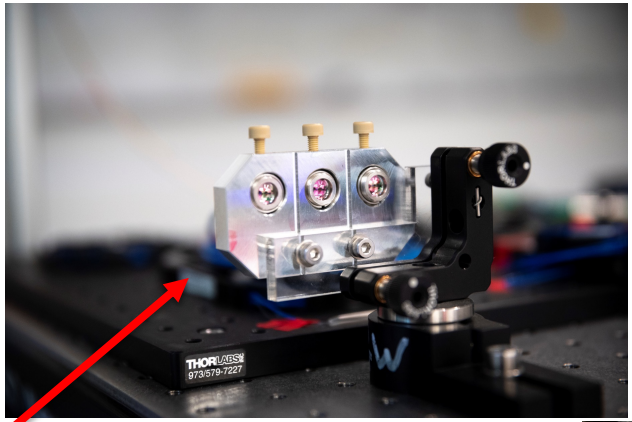
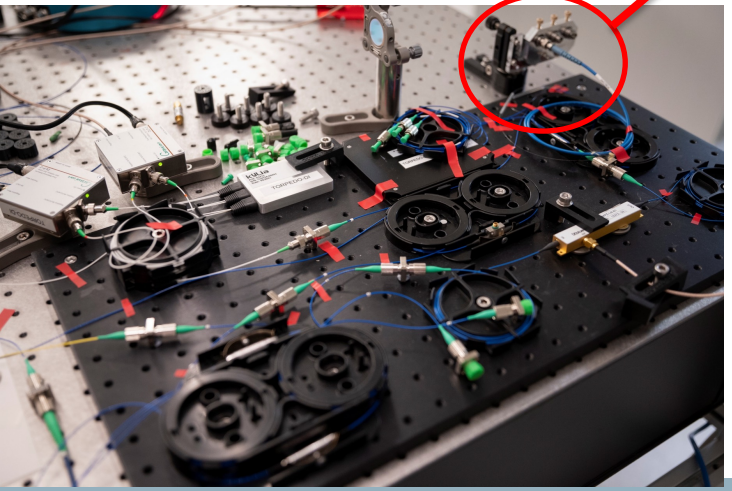
Taking it into the lab

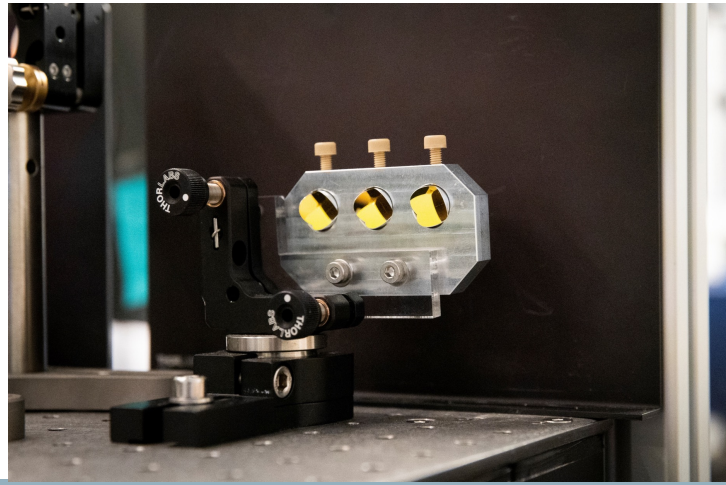


Fibre collimator/partial reflectors

Input & output optics

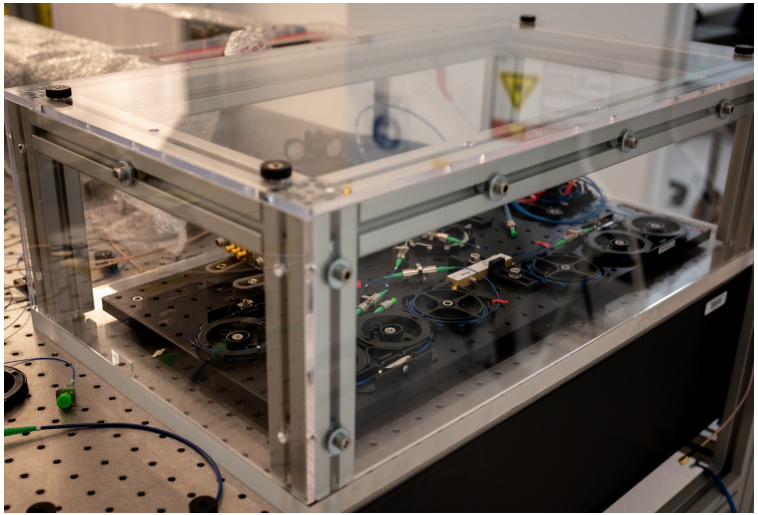


Final reflectors

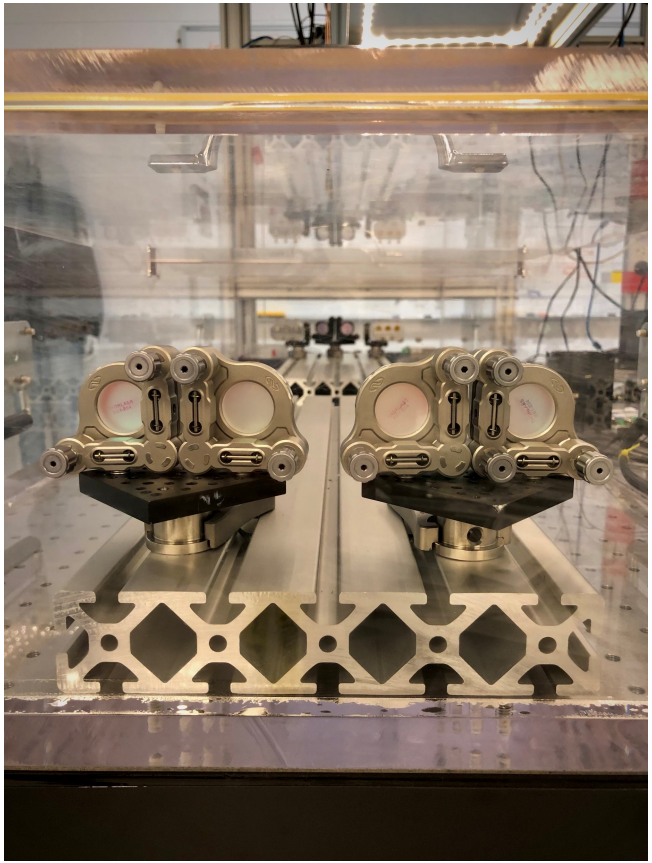


Thermal Insulation – V1

Enclosure for input optics – portability

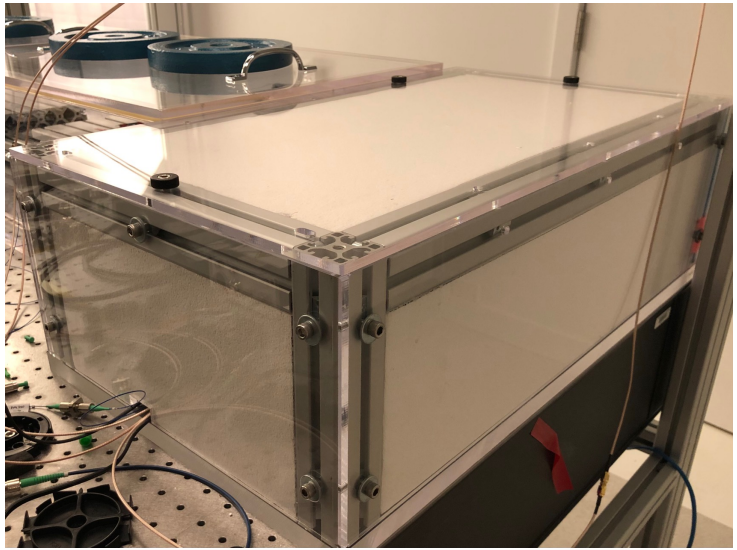


Thick Perspex enclosure
To remove air current

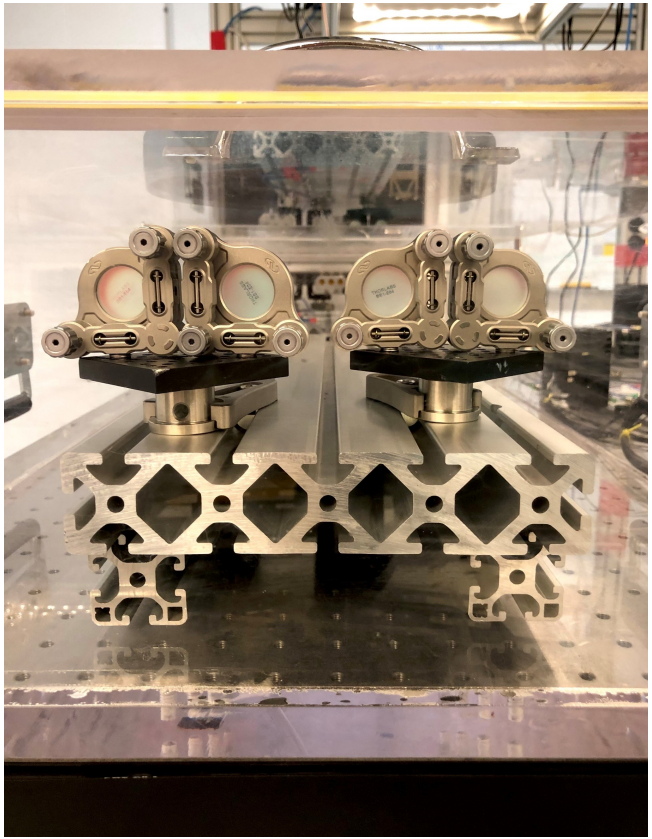


Thermal Insulation – V2

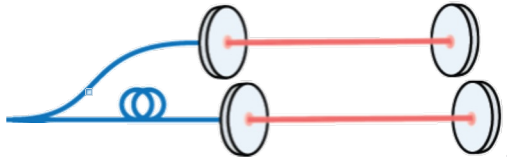
Added polystyrene – now an esky

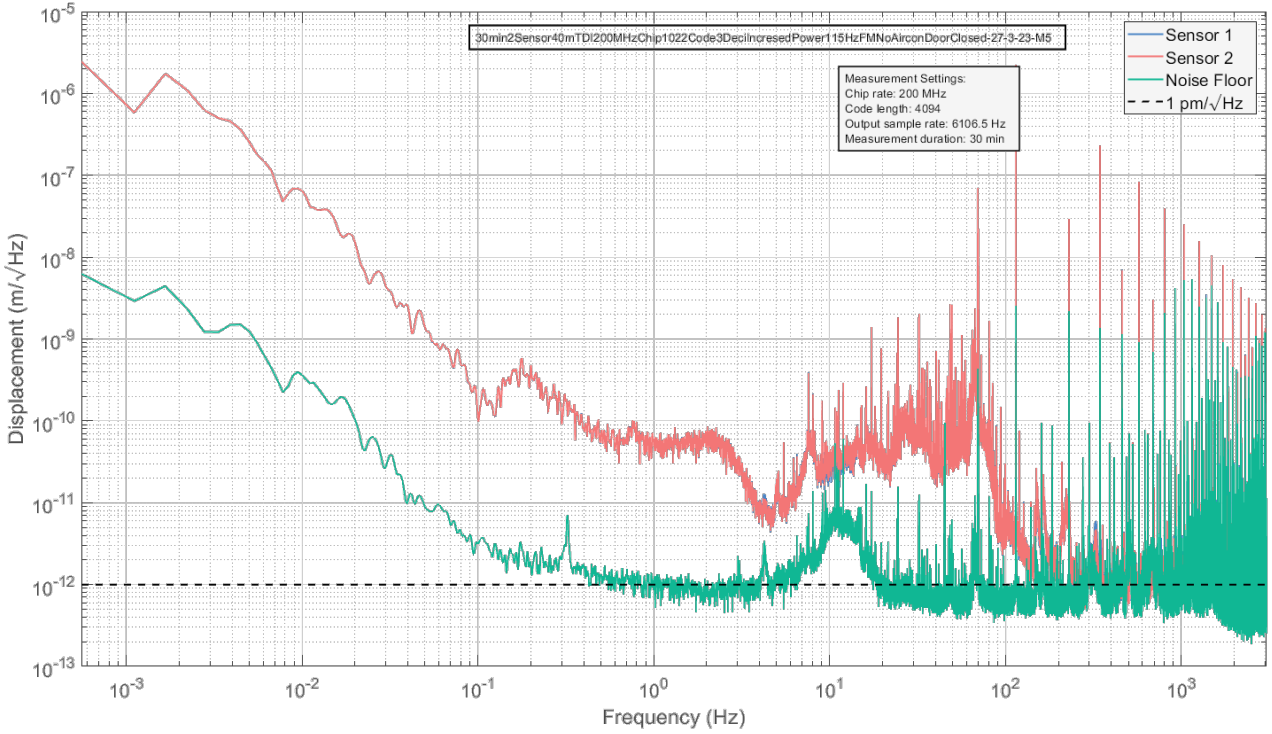


Added mechanical isolators



Readout and Sensitivity





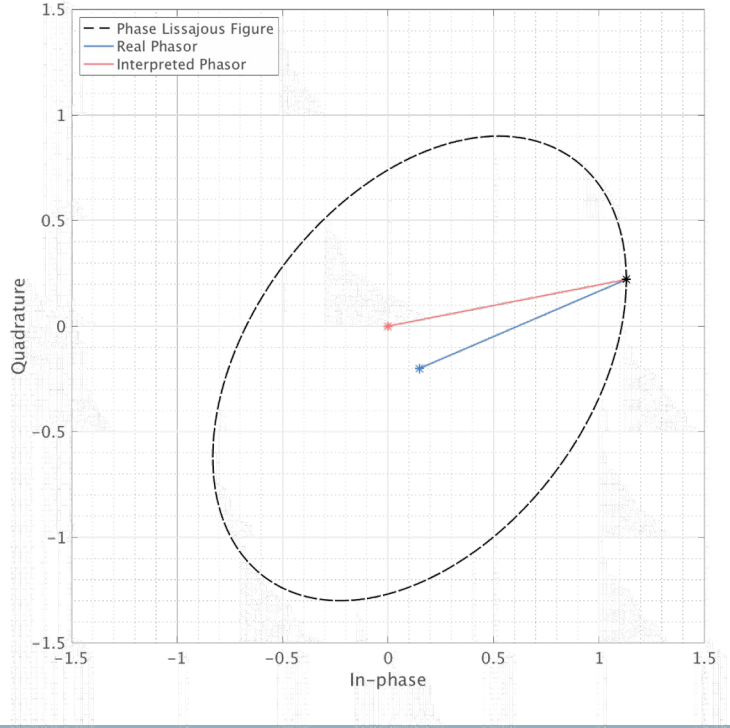
2 sensors to test the noise floor

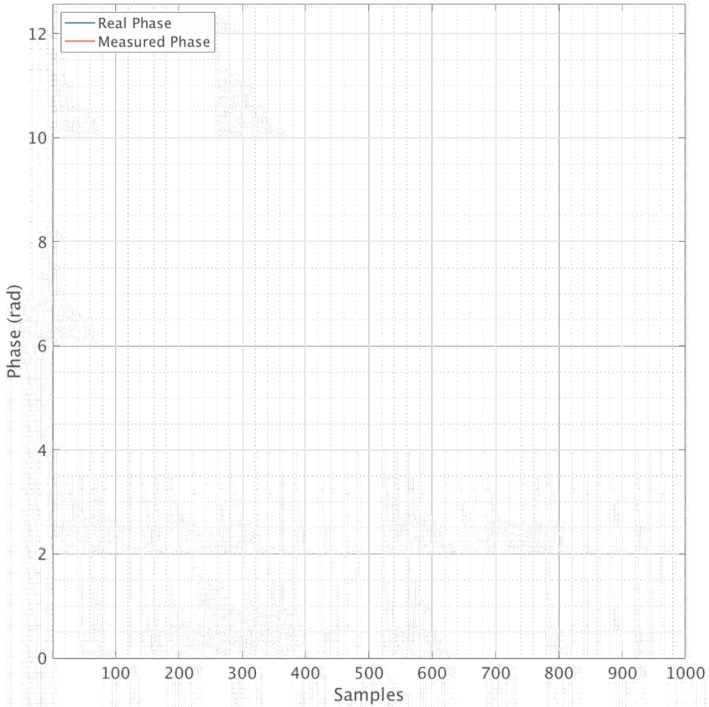
1 pm/√Hz above 0.5 Hz
10 pm/√Hz at 40 mHz

Low-freq roll-up likely due to residual thermal (convection, temperature) effects.

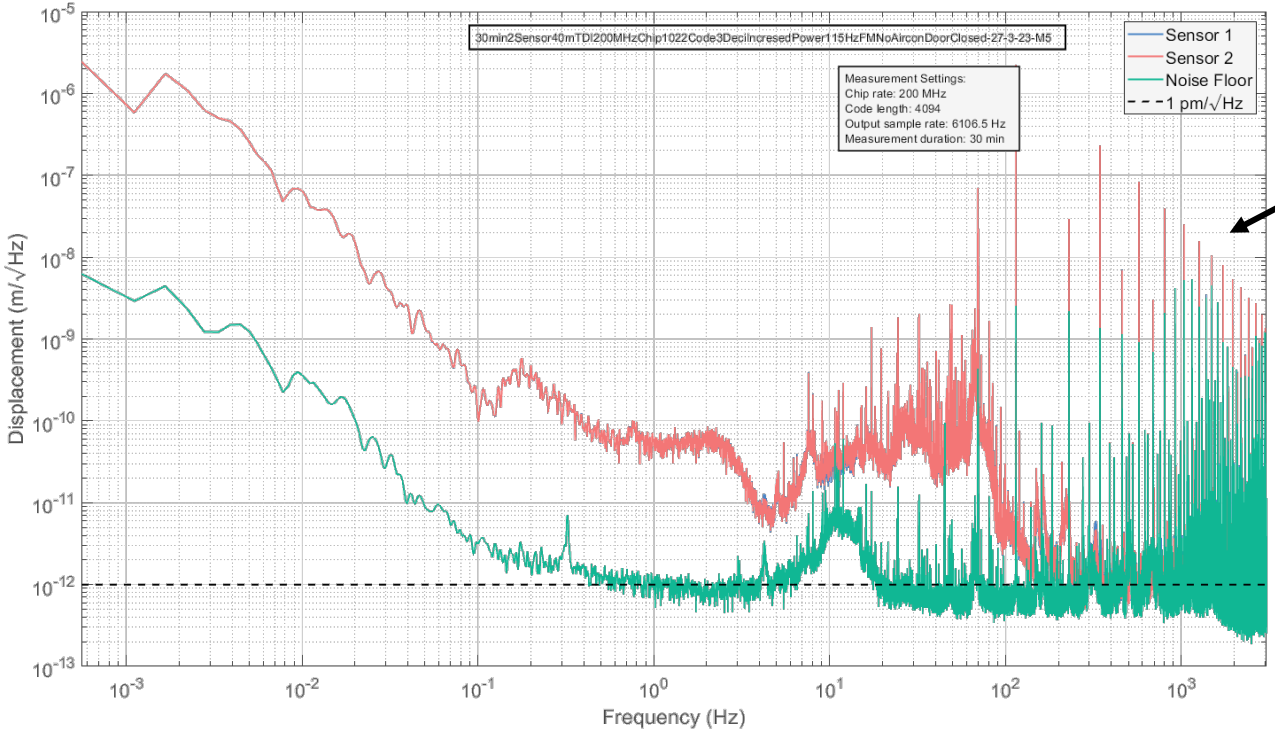
Using a frequency chirp to collect cyclic error (next slide)

Cyclic Error





Cyclic Error

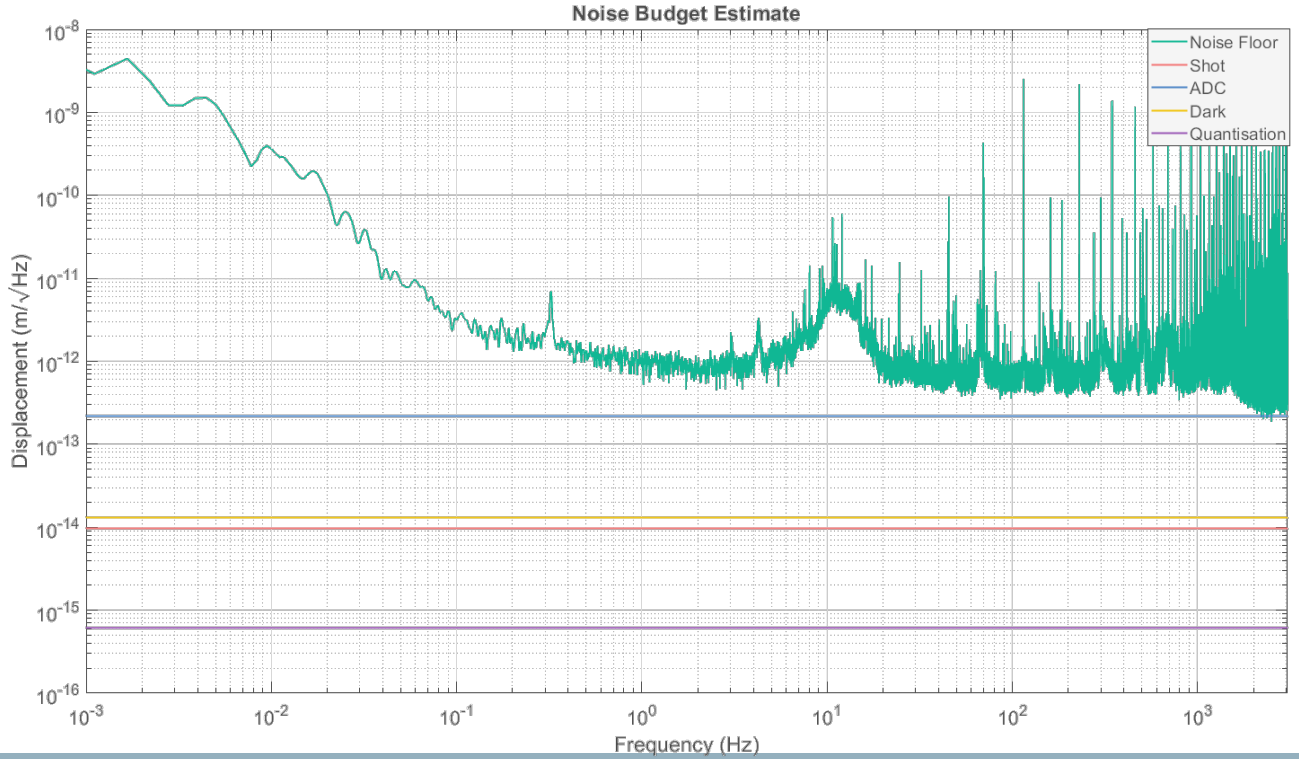


FPGA algorithm* will hopefully correct cyclic error in real-time.

No need to chirp anymore.

*Hu P, Zhu J, Guo X, Tan J. Compensation for the variable cyclic error in homodyne laser interferometers. Sensors (Basel). 2015 Jan 30;15(2):3090-106. doi: 10.3390/s150203090. PMID: 25647739; PMCID: PMC4367349.

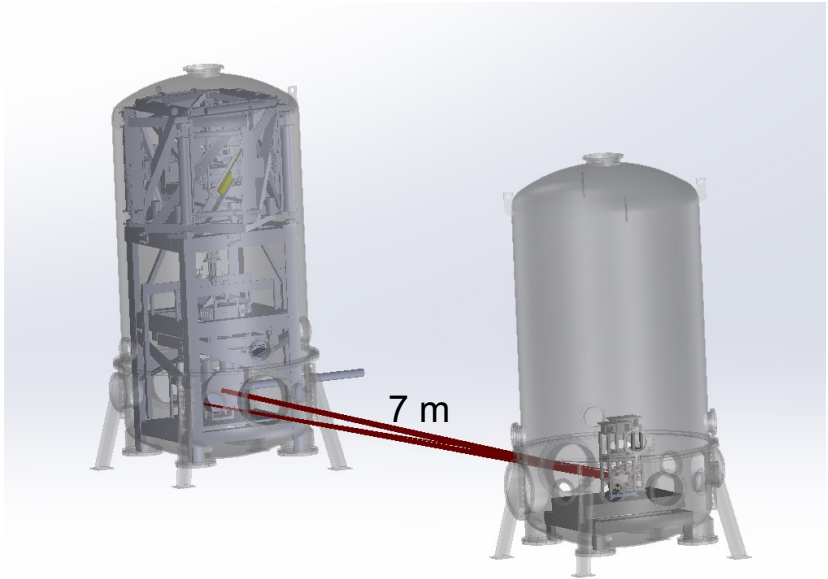
Noise Budget

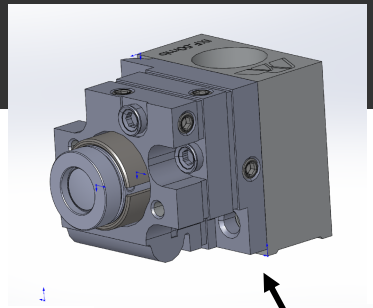


ADC front end noise is the highest broadband noise.

Note: ADC NEP is usually quoted for high frequencies. DI demodulation is a practice of spectral redistribution. This couples in the much higher, low-frequency ADC noise.

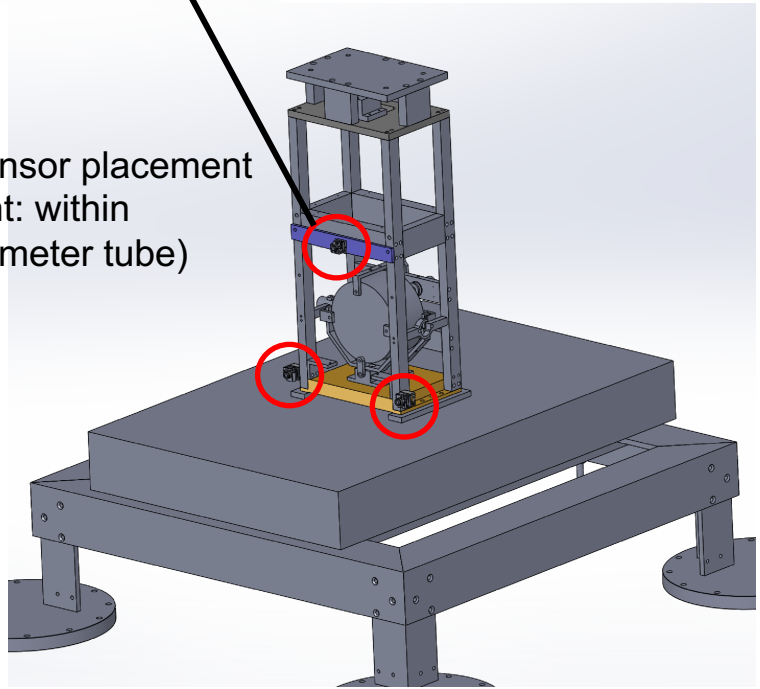
Upcoming Work – Gingin 7m Cavity Test





Size: about 1 in (w) x 1 in (h) x 1.2 in (d)

Intended sensor placement (requirement: within 400 mm diameter tube)



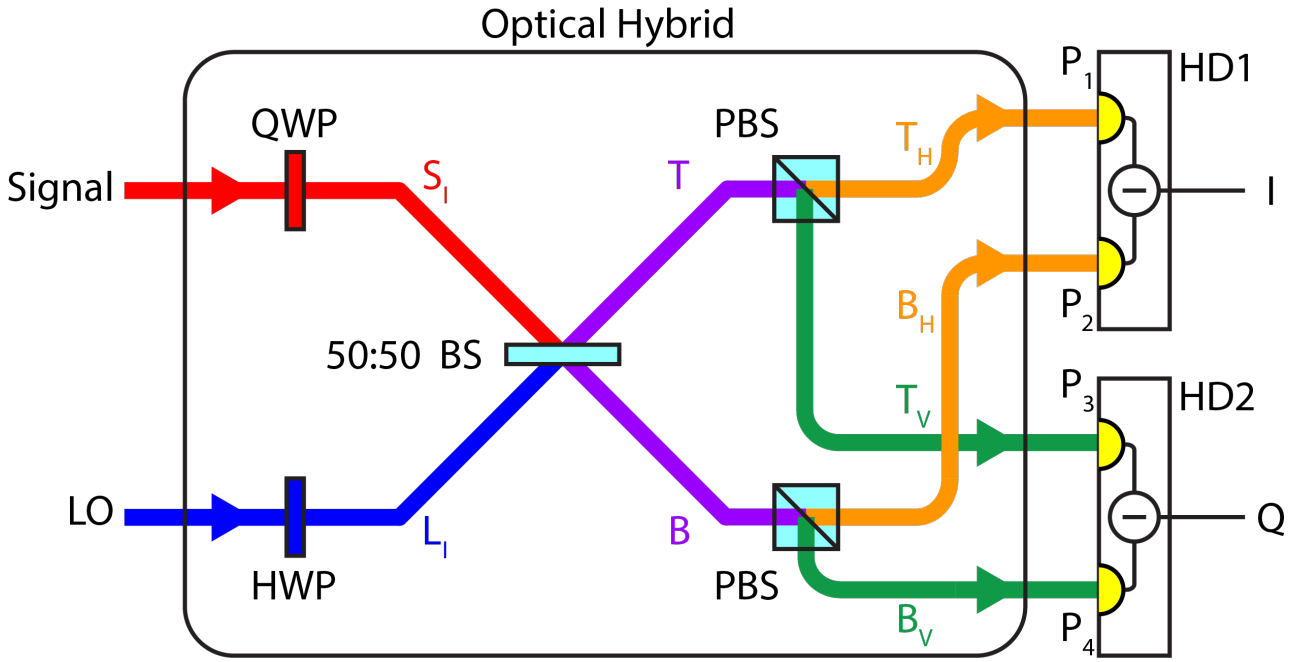
Goal: to assist with platform stabilisation, reduce coupling and ease locking requirement.

Challenges

- Difficulty quantifying improvement from SPI
- Sufficient signal bandwidth
- Cyclic error
- Signal transfer between current implementation (LabView FPGA) to CDS
  - Reflective Memory
- In-vacuum fibre couplers
  - Testing Thorlabs
- Need fibre splicing (e.g. no connectors)

thanks

Optical Hybrid



Seismometer Overlay