Sensing seismic platform relative motion using Digital Interferometry

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GWADW 2021
(Remote, 17th - 21st May)
LIGO Document: G2100987

Context

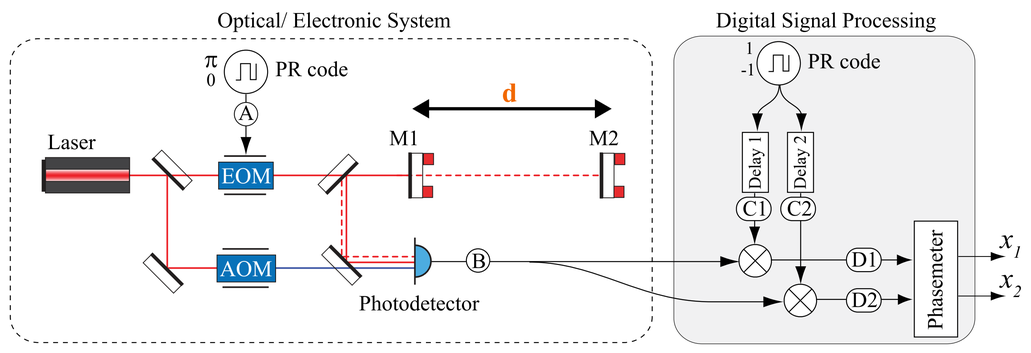
Gravitational-wave interferometric detectors have many internal seismic platforms to support the various suspended optics. For future detectors, the relative motion of these seismic platforms, via coupling to the auxiliary length controls of the suspended optics, are predicted to be the limiting noise source at low frequencies below 1 Hz [1]. By measuring, then stabilizing the relative motion between the seismic platforms, the effective control feedback to the optics will be reduced and hence the noise coupling will be less, and potentially improve detector noise performance. The measurement of the relative motion with forms of suspension platform interferometry (SPI) is an ongoing area of research and development [2].

Digital Interferometry (DI)

Digitally-enhanced interferometry or Digital Interferometery (DI) provides a way to isolate interferometric signals based on their delay [3], shown in Figure 1.

- Achieved measured displacement sensitivity of Δd = 1 pm/√Hz down to 1 Hz in 2009 [4].

- Since then, advancements include:
  - Technique: DSP efficiency, Multiplexing analysis [5]
  - Applications: Optical phased arrays [6], Fiber frequency references [7], Multi-mirror sensing [8]



	Decoding delay optimized for M1	Decoding delay optimized for M2
Conventional heterodyne		
PR encoding	A	A
Detected signal from M1	B	B
PR decoding	C1	C2
Decoded output	D1	D2

Figure 1: Concept of DI. Light is time-tagged by pseudorandom (PR) phase modulation (A). With correct delay (C1), the signal of interest is isolated (D1).

DI for Suspension Sensing at the ANU

Part of the Torsion Pendulum Dual Oscillator (TorPeDO) Newtonian Noise sensing program.

- See GWADW 2021 talk by N. Holland [9].

Goal: To replace the displacement sensors in the TorPeDO suspension system, shown in Figure 2. Target requirements shown in Table 1 [10].

- Leverage optical simplicity and multiplexing

Test experiments in progress, shown in Figure 3, with designs for implementation underway.

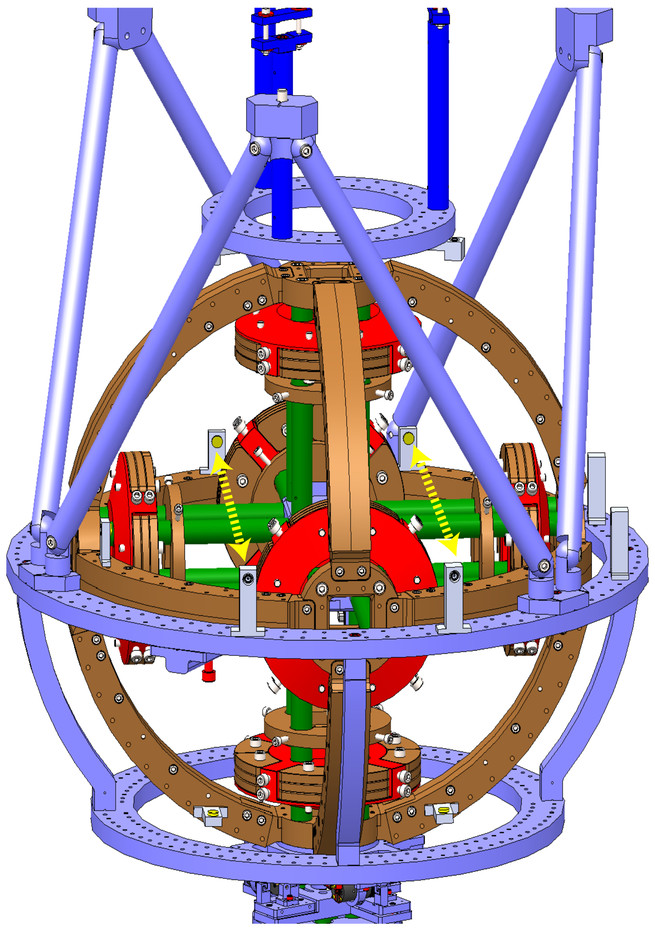
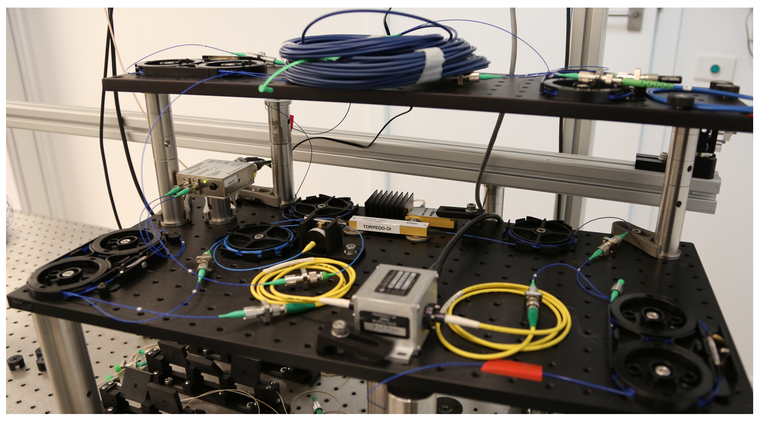


Figure 2: Conceptual view of DI sensing between Inverted Pendulum lower frame (blue) and sphere of the Intermediate Mass (brass) of the TorPeDO suspension. Yellow arrows indicate an example measurement direction.



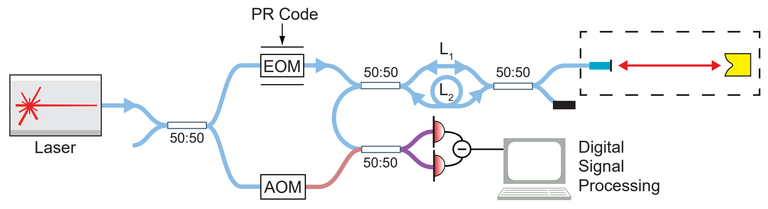


Figure 3: First test setup. Fiber-based, with collimator and reflector being the "DI mirrors M1 / M2". Simplified schematic shows dotted box outlining the 'sensor' - only part that will eventually go under vacuum. Different optical delays (L_1, L_2) allows two DI measurements of the same sensor. Photo above shows fibered modulators, subtracting PD and optical delay fiber coil.

Prospectives towards DI for SPI

Possibilities for using DI in SPI-type sensing [10]:

- Length sensing between seismic isolation platforms, or even groups of seismic isolation platforms with different DI code delays.
- Length sensing between intermediate suspension stages of the optics directly.

Table 1 compares parameter targets - Lessons from TorPeDO to feed into SPI concepts

Parameters	TorPeDO Target	SPI-type Target	Comment
Wavelength	1550 nm	1550 nm	Same wavelength
Signal Power	< 10 μW	< 10 μW	Same target
Displacement Δd	1 pm/√Hz at 0.1 Hz	1 pm/√Hz at 0.1 Hz	Same target
Separation **d**	0.50 - 0.75 m	~ 5 m to ~ 4000 m?	Less restrictive for SPI
Signal Processing	CDS / Labview	CDS / Open software	Lessons to feed in
Multiplexing Sensors	2, 3, or 9 channels	To be determined	Lessons to feed in

Table 1: Parameters and Targets comparison in the TorPeDO and SPI contexts for sensing using the Digital Interferometry technique

References

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