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Characterization of heterodyne phase locking for a Newtonian noise sensor

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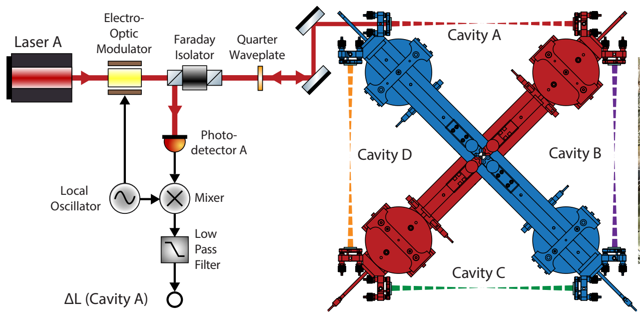
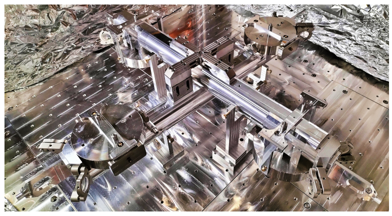
Newtonian Noise

Newtonian noise, also known as gravity gradient noise, is a potential limiting noise source for future detectors at frequencies below 20Hz. Newtonian noise is caused by shifts in the local density profile of matter around a gravitational wave detector, which gives rise to gravitational field fluctuations that induce time-dependent net forces on the test mass mirrors of the detector [1]. An array of low-frequency sensors positioned around GW detector test masses will help directly measure and then subtract the Newtonian noise contribution from the detector's final readout. Here at the Australian National University (ANU), such a low frequency Newtonian noise sensor is being constructed called the ***Torsion Pendulum Dual Oscillator*** *(TorPeDO) [2].*

TorPeDO design and optical readout

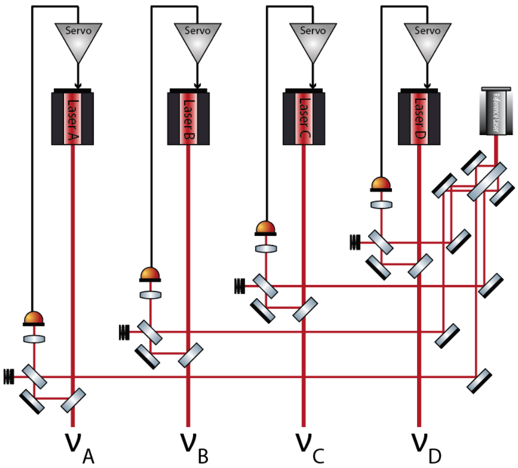
The sensor comprises of two freely suspended perpendicular torsion bars and they differentially rotate in response to Newtonian fluctuations. The differential angle is optically measured via length changes of four Fabry-Perot cavities formed around the two torsion bars. The Pound-Drever-Hall technique is used to interrogate each cavity with an individual laser.





Heterodyne Phase-locking fo TorPeDO readout lasers

The free-running frequency noise of readout lasers will dominate the sensor readout. To mitigate this, we employ a simultaneous heterodyne phase-locked loop (PLL) for each of the four readout lasers, locking them to a common fifth reference laser. Figure shows the optical setup with control electronics of heterodyne phase-locking of the four TorPeDO readout lasers (A, B, C and D) to a common reference laser. The reference laser beam is split into four beams to interfere with each of the readout laser beams. Each optical beat note is detected by a photodetector and subsequently injected into a digital servo. The servo generates an error signal to feedback and actuate to the readout lasers to lock them to the reference laser. By phase-locking all four readout lasers, they follow the same laser frequency noise characteristics of the reference laser and their noise contribution can be suppressed.



To the optical readout system of TorPeDO

PLL Characterization

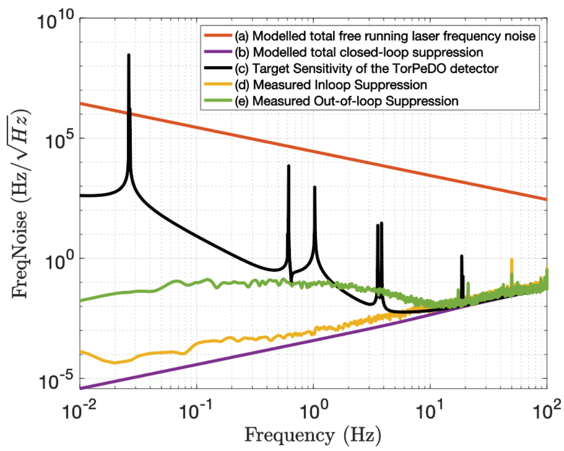


Figure shows models of (a) total quadrature sum of free-running laser frequency noises of the four NPRO readout lasers [3][4]. Curve (b) shows total quadrature sum of suppressed laser frequency noise by employing heterodyne phase-locking. Curve (c) is the target sensitivity of the TorPeDO sensor in equivalent laser frequency noise units. TorPeDO is expected to reach a target sensitivity that is a combination of thermal noise for the current generation of TorPeDO detector (using tungsten suspension wires), readout shot noise and frequency noise from readout lasers. The plot shows the (d) measured in-loop frequency noise performance and (e) measured out-of-loop frequency noise performance.

Conclusion and Future work

Here we have demonstrated the stable operation of four simultaneous heterodyne phase locking of TorPeDO readout lasers. The closed-loop measurements achieve sufficient suppression and out-of-loop residual frequency noise reaches below the target sensitivity at frequencies below 1 Hz. Achieving the performance at 10 Hz requires further investigation. Employing PLLs in TorPeDO readout is required to reach the thermal noise-limited target sensitivity.

References: [1] S. S. Y. Chua et al. Appl. Phys. Lett. (2023)
[2] D. J. McManus et al. J. Phys. Conf. Ser. 716:012027 (2016)
[3] M. Trobs et al. J. Phys. Conf. Ser. 154:012026 (2009)
[4] P. Kwee & B. Willke Appl. Opt 47 (2008)