Multi-Spatial Mode Readout Of Optical Cavities For Reduced Brownian Coating Thermal Noise

Jue Zhang,[1,2,3] Namisha Chabbra,[1,2,3] Andrew R. Wade,[1,2,3] and Kirk McKenzie[1,2,3]

1. Centre for Gravitational Astrophysics, Research School of Physics, The Australian National University, Canberra ACT 2600, Australia.

2. ARC Centre of Excellence for Engineered Quantum Systems (EQUS), Research School of Physics, The Australian National University, Canberra ACT 2600, Australia

3. ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), Research School of Physics, The Australian National University, Canberra ACT 2600, Australia

ARC Centre of Excellence for Gravitational Wave Discovery

Australian Research Council Centre of Excellence for Engineered Quantum Systems

ANU CENTRE FOR GRAVITATIONAL ASTROPHYSICS

Australian National University

Abstract

Active **laser stabilisation** ties a laser's frequency to an ultra-stable reference, such as an optical resonator, by comparing the frequency of the laser to the reference and using feedback control to regulate the laser.

Coating Brownian thermal noise, arising from random Brownian motions of the mirror coating materials, is the main limitation of precision measurements at frequencies below 10 Hz.

We proposed a **multi cavity transverse mode readout scheme** [1] that realises an equivalent thermal noise level of a mesa flat-top beam, which is well known to be efficient at thermal noise reduction compared to a conventional Gaussian beam by effectively increasing the sampling area, yet has technical difficulties in generation. With optimal weighings of different spacial modes, this novel approach allows us to improve the coating thermal noise by a factor of 2.46 with 25 modes and 1.61 with 3 modes in short cavities.

Methodology

- digitally synthesizing a flat-top beam by adding multiple higher order modes
- more averaging of thermal noise on the mirror surface
- an improvement of 1.6 for just three optical modes
- equivalent to cooling to 120K.

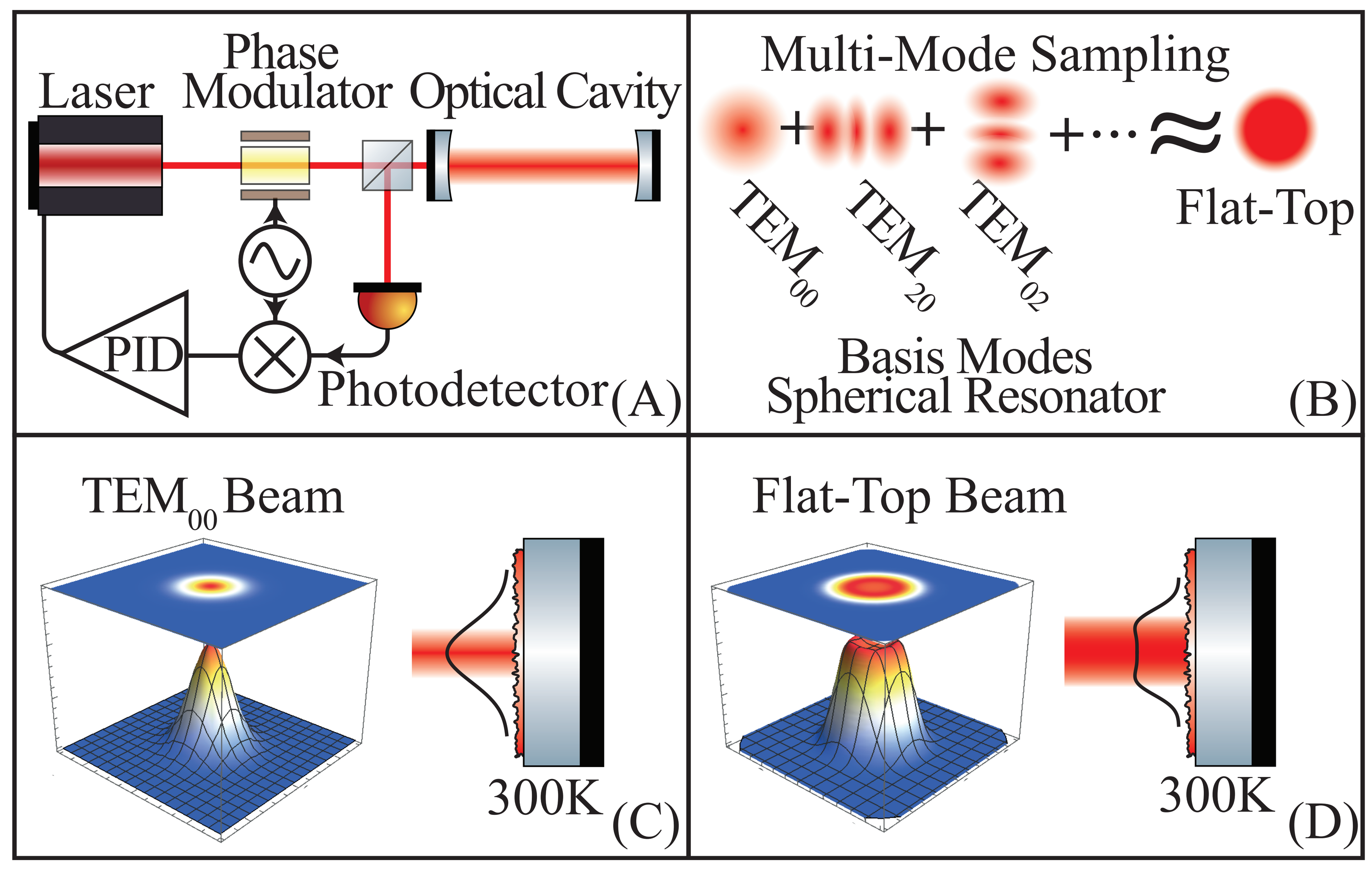


Figure 1: Utilising multiple modes together will reduce Brownian noise in coatings

Experimental Set Up

- Each Hermite Gaussian modes locked to the test cavity via Pound-Drever-Hall (PDH) technique
- AOM: generating frequencies matching the higher order mode resonances
- EOM: generating modulation sidebands for PDH
- Weighing equivalent to a mesa beam
- PID servo for stable feedback
- Field Programmable Gate Array (FPGA) for modulation and digi-

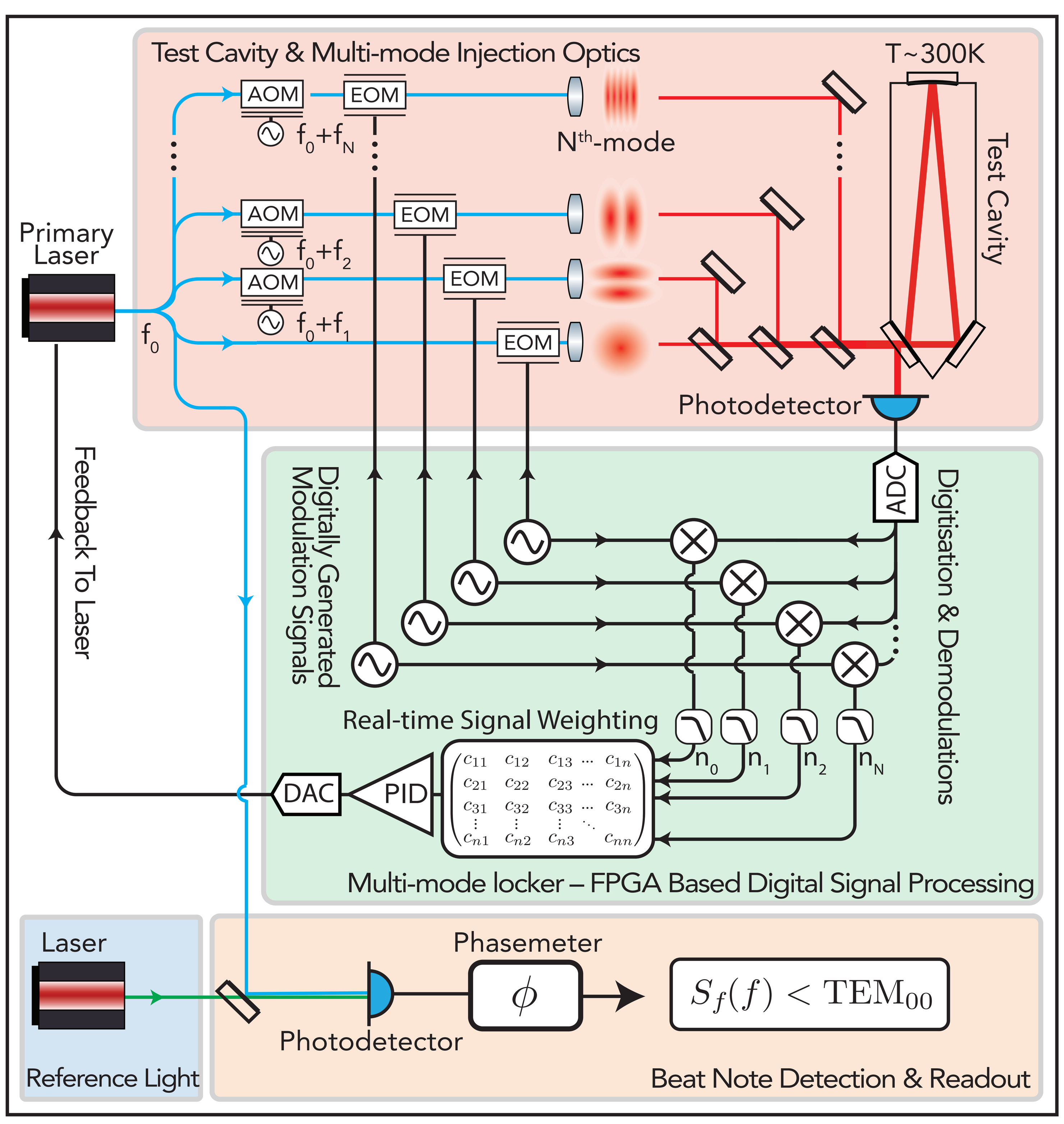
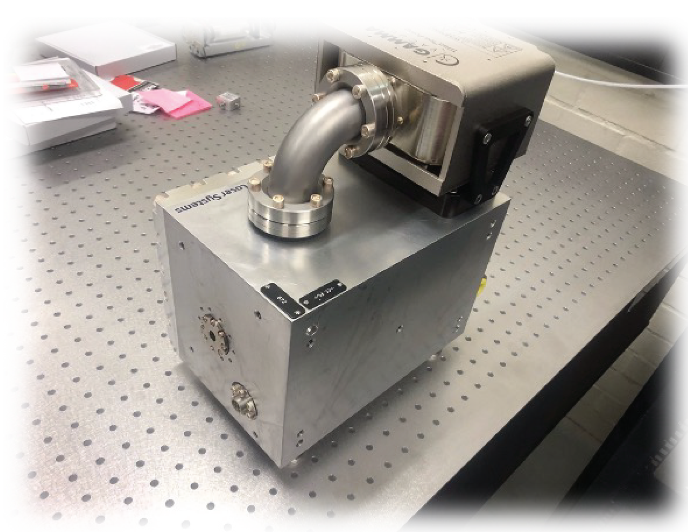


Figure 2: Experimental set up for proposed experiment

Reference laser performance

- Reference laser performance 00x00 two laser one cavity beat note
- Cavity common noise immune
- Below thermal noise
- 00x02 result
- – need more work



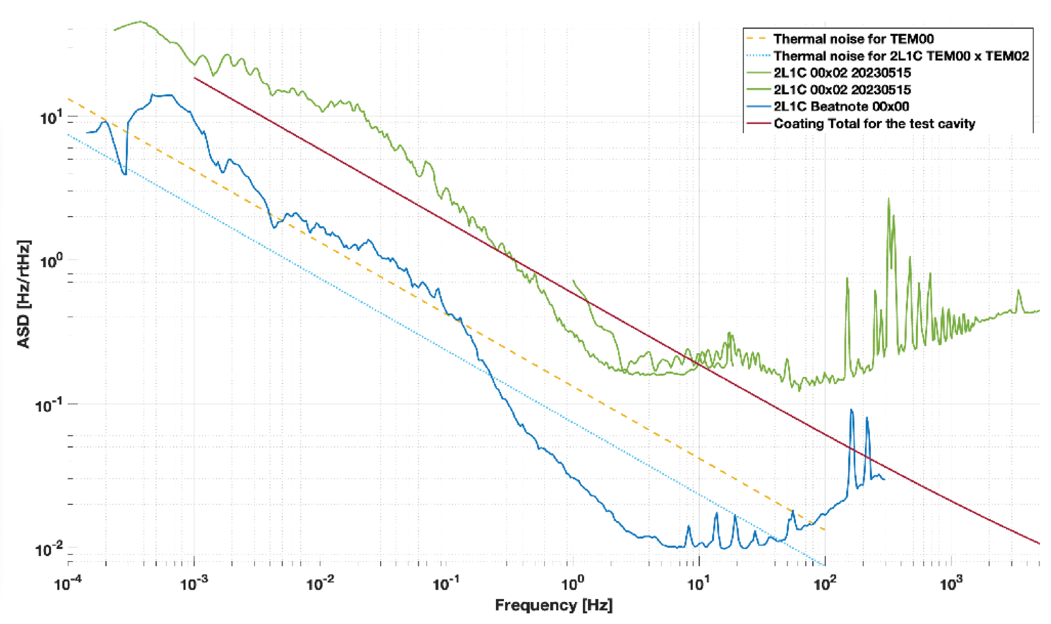


Figure. 3: High finesse cavity   Figure. 4: Reference laser performance

Test Cavity Design

- Goal: a cavity with high Coating Brownian noise
- Spacer & substrate material: ULE
- Coating properties: alternating layers of SiO2 (1/4 λ) and Ta2O5 (3/4 λ)
- Cavity geometry: Folded cavity, flat x 1, curved x2
- ROC: 50 mm
- Cavity length: 50 mm
- Round-trip length: 100 mm
- Beam size: 87.0239 um
- Thermal noise @ 1Hz: 1.1967 Hz/ √Hz
- Similar design to Gras et. al. [2]

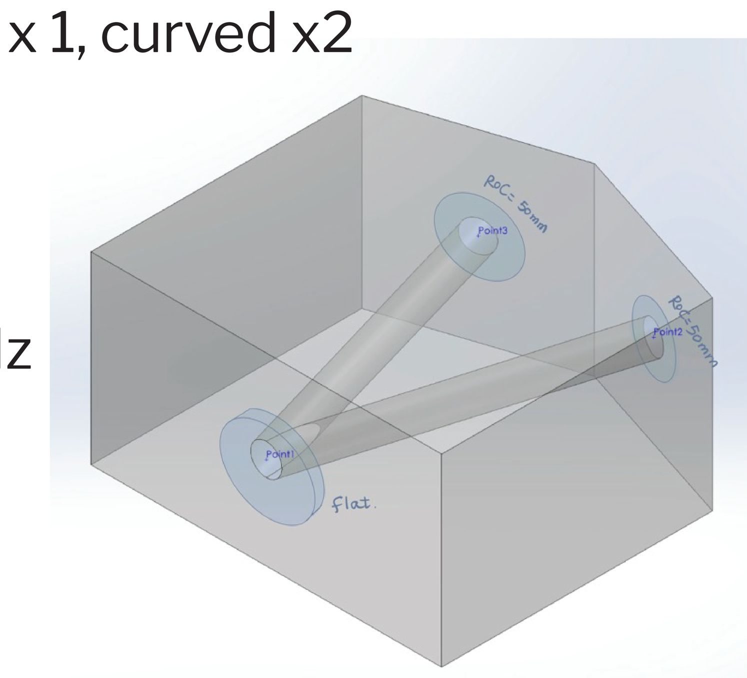


Figure. 5: Current cavity design

[1] Andrew Wade and Kirk McKenzie, "Mirror coating-thermal-noise mitigation using multi-spatial-mode cavity readout," Phys. Rev. A, 106(2) (2022).
[2] S. Gras and M. Evans, Phys. Rev. D 98, 122001

jue.zhang@anu.edu.au