Digital Interferometry for Lock Acquisition in Advanced LIGO

David Rabeling
Centre for Gravitational Wave Physics
The Australian National University in Canberra

David.Rabeling@anu.edu.au

Thanks for ongoing support from:
- The LIGO laboratory
- The Australian Research Council

LIGO-G070788-00-Z

Overview

- Motivation for this work
- Heterodyne interferometry
- Digital modulation and demodulation
- Results

THE AUSTRALIAN NATIONAL UNIVERSITY

Motivation: Previously identified problems for Lock acquisition in advanced LIGO

- Test masses are swinging randomly with respect to each other at ~10^{-7}m (< 0.5 Hz).
- Test mass actuator are limited in control force which makes it difficult to reduce large test mass velocity [Osamu].

Differential motion of arm cavity test masses could be reduced by SPI [Drever, Aso]. This will aid in locking the arm cavity DOFs.

General problems for lock acquisition in advanced detector configurations

- Control systems for ground based gravitational wave detectors are typically custom designed to suit each configuration, often requiring matching of modulation frequencies to interferometer lengths. Many DOF signals are interdependent, exhibiting large cross-talk between measurements.
- linear error signals are obtained only within a small range near the desired operating point.

Lock acquisition is becoming a significant challenge as the complexity of interferometer configurations increases.

A possible solution for lock acquisition in advanced LIGO

Goal: To design a system that can aid in lock acquisition for advanced detector configurations.

Requirements:

- Needs a large dynamic range compared to standard control systems used.
- Aim to reduce relative displacement between the arm cavity test masses to from several μm to 1nm between 10^{-2} and 10 Hz.

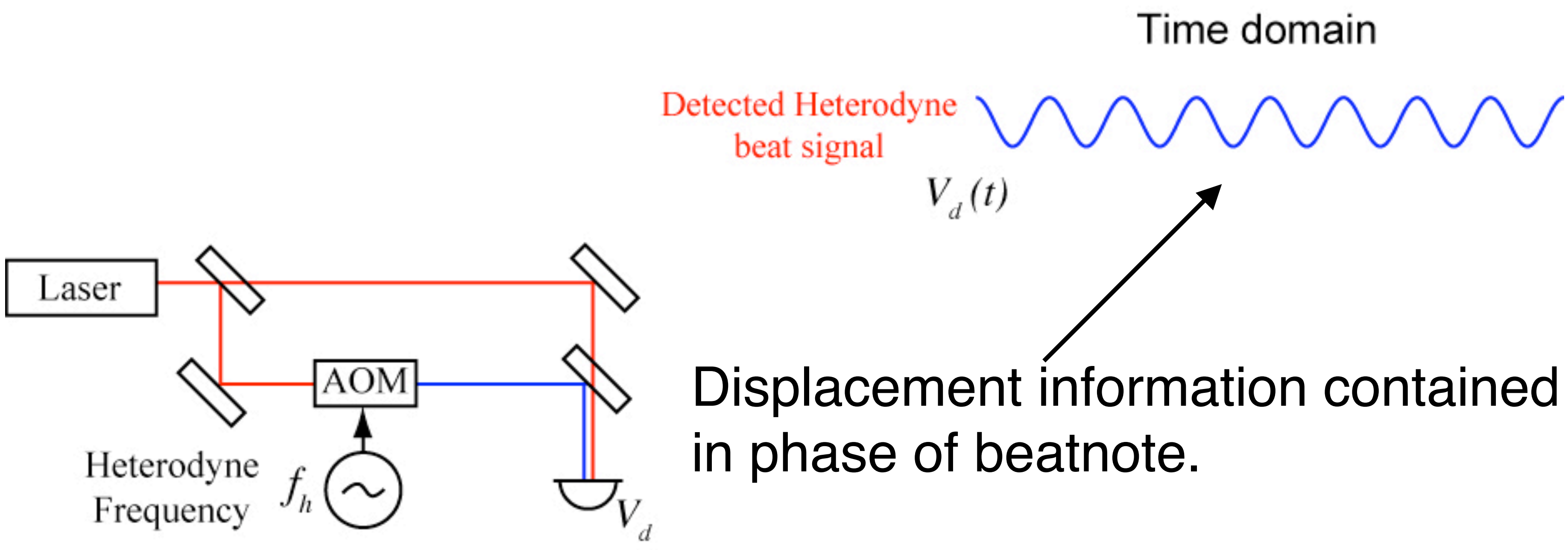
Heterodyne interferometry for displacement measurements

- Measures the phase of a beatnote between two frequencies. LISA's main optical measurement system is a Heterodyne measurement which can track pico-meter displacement over 50,000km.

  Recalling the previous slide: reduce relative displacement between the arm cavity test masses to 1nm between 10^{-2} and 10 Hz over several μm.

Combining standard Heterodyne interferometry with digital modulation

Standard Heterodyne setup



Displacement information contained in phase of beatnote.

Isolation of individual optical path lengths

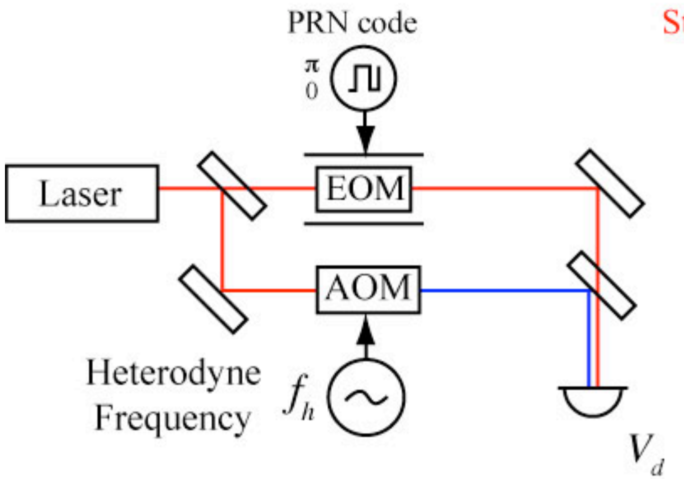
- We apply digital Pseudo Random (PR) phase modulation which flips the phase by either 0 or π.

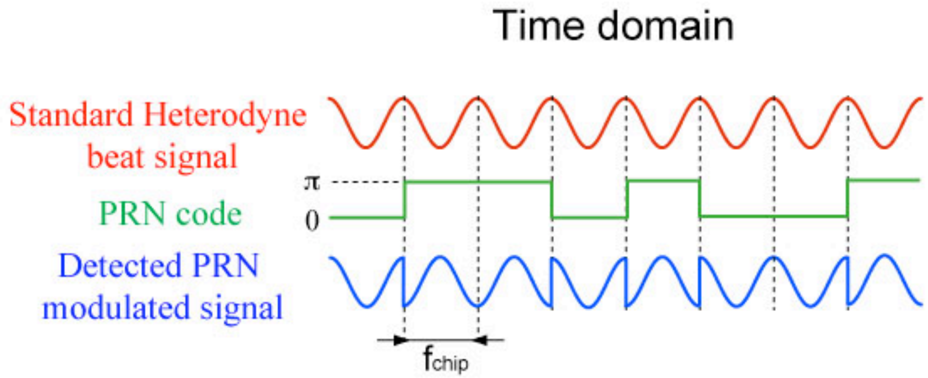
Isolation of individual optical path lengths

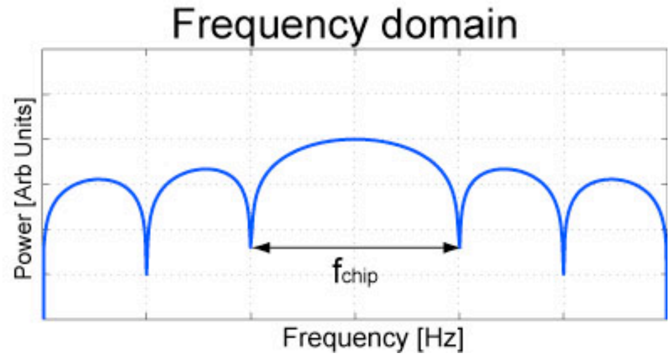
- We apply digital Pseudo Random (PR) phase modulation which flips the phase by either 0 or π.
- By PR modulation the entire carrier power is spread over a large frequency range and appears as broadband noise.

Combining standard Heterodyne interferometry with digital modulation

Pseudo random noise phase modulation





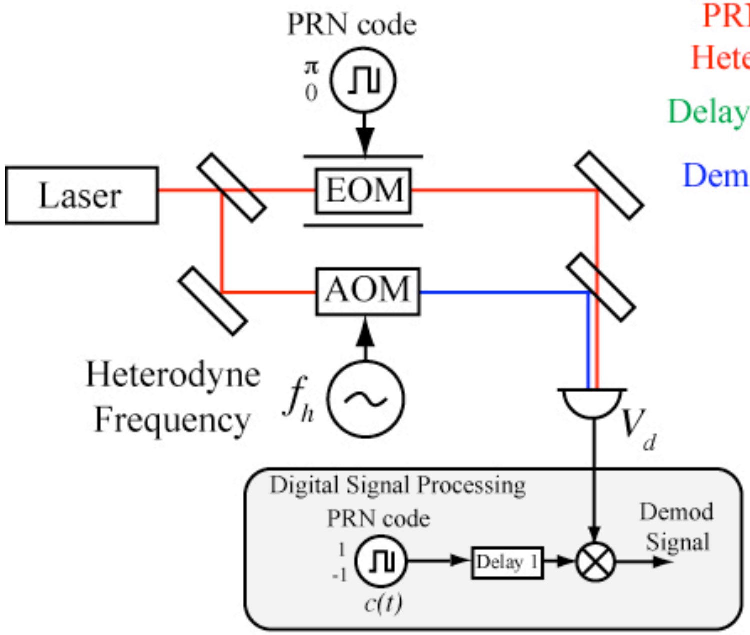


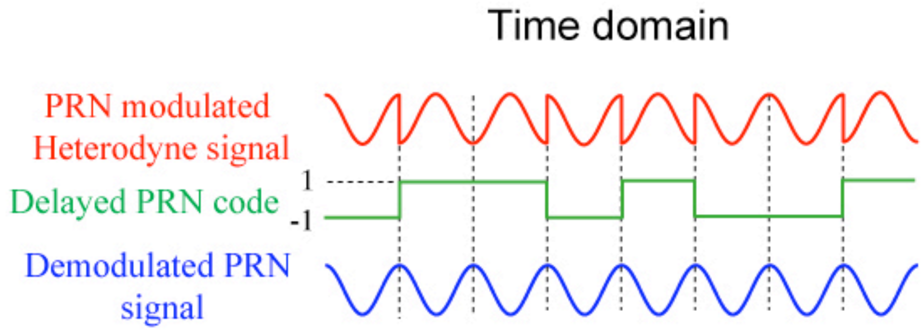
Isolation of individual optical path lengths

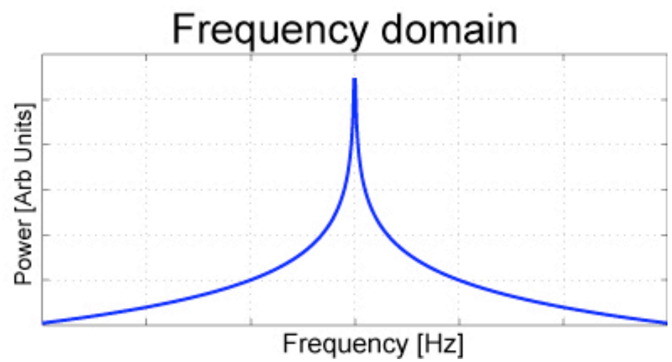
- We apply digital Pseudo Random (PR) phase modulation which flips the phase by either 0 or π.
- By PR modulation the entire carrier power is spread over a large frequency range and appears as broadband noise.
- Demodulation with a code that matches the optical and electronic delay recovers the original heterodyne signal for the optical path length with the same delay.

Combining standard Heterodyne interferometry with digital modulation

Demodulation with an appropriately delayed version of the code





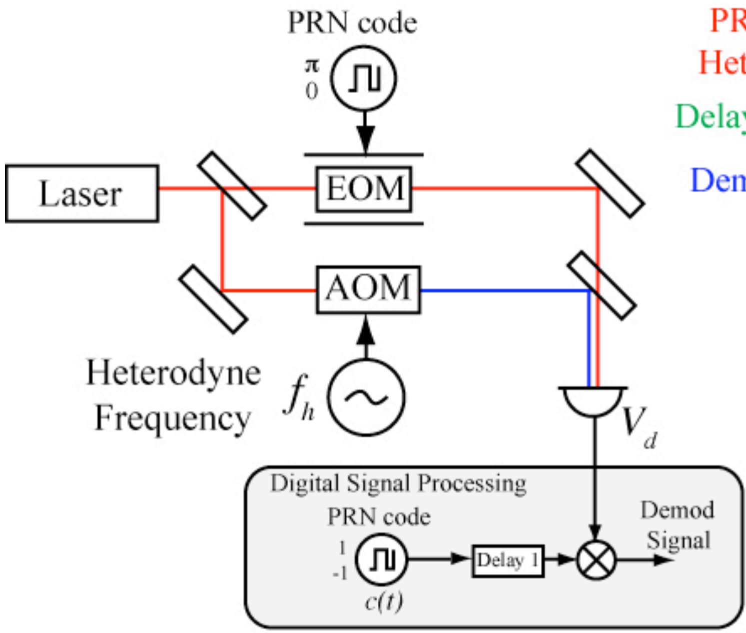


Isolation of individual optical path lengths

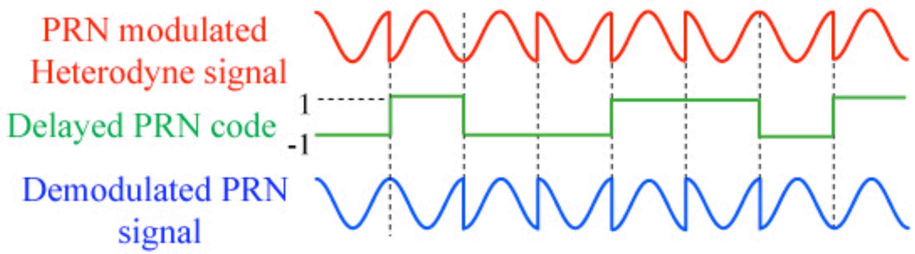
- We apply digital Pseudo Random (PR) phase modulation which flips the phase by either 0 or π.
- By PR modulation the entire carrier power is spread over a large frequency range and appears as broadband noise.
- Demodulation with the same code and that is matched to the optical and electronic delay recovers the original heterodyne signal for the optical path with the same delay.
- But demodulation with a mismatched delayed code remains broadband noise.

Combining standard Heterodyne interferometry with digital modulation

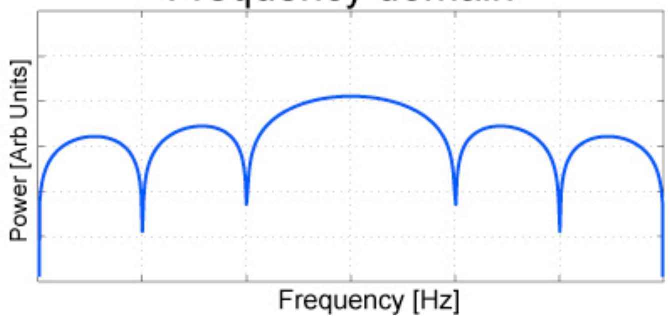
Demodulation with a mismatched delayed version of the code



Time domain



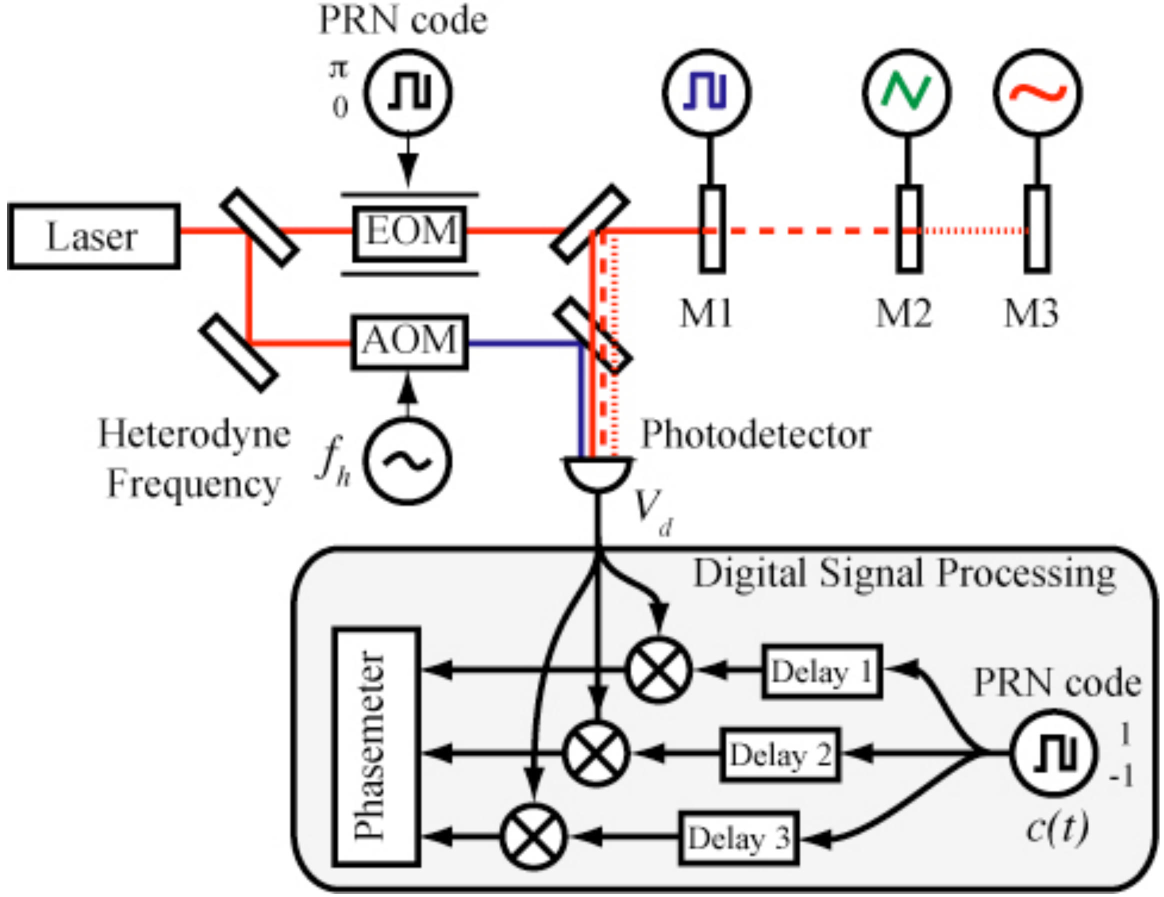
Frequency domain



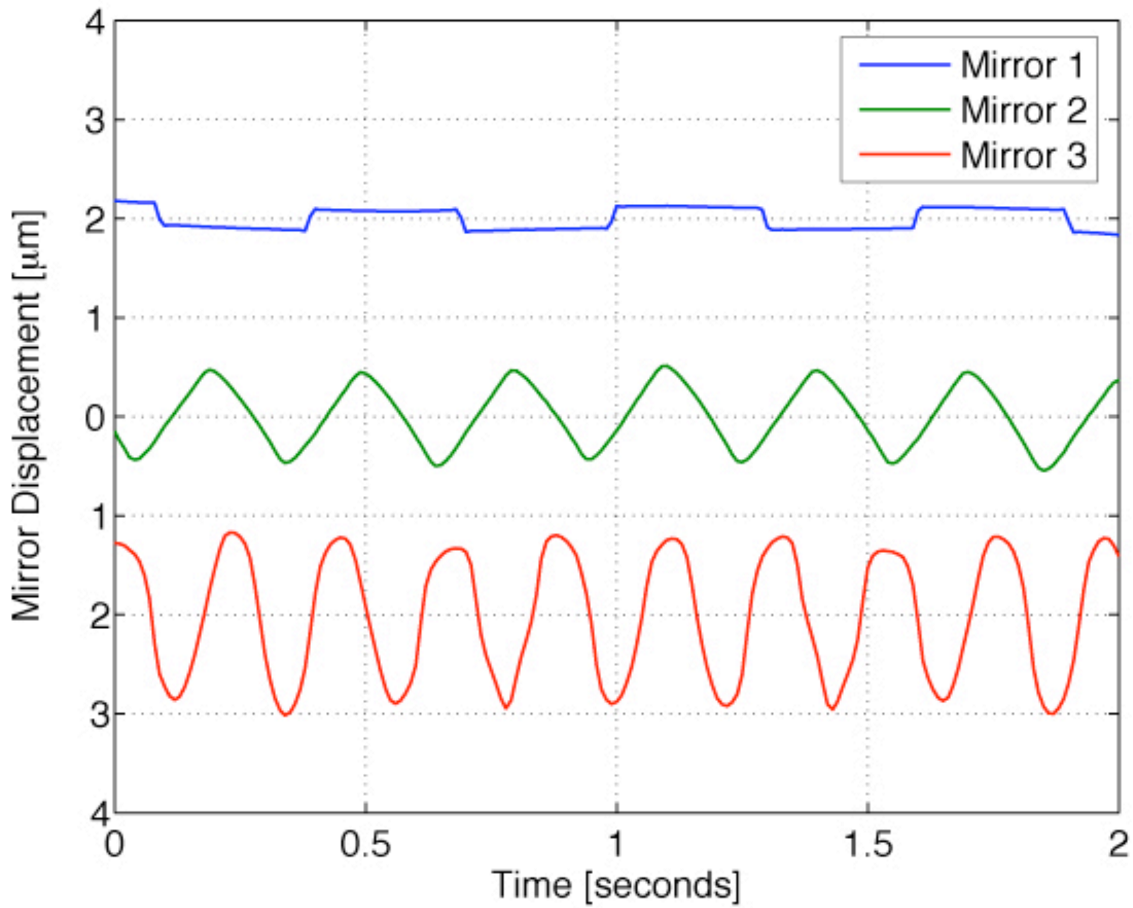
First test of the Digital Interferometry

1. Test if can address and measure individual optics in a multi mirror configuration.
2. Test interferometer performance and determine limiting factors that might limit current displacement sensitivity.

Use for multi element interferometers

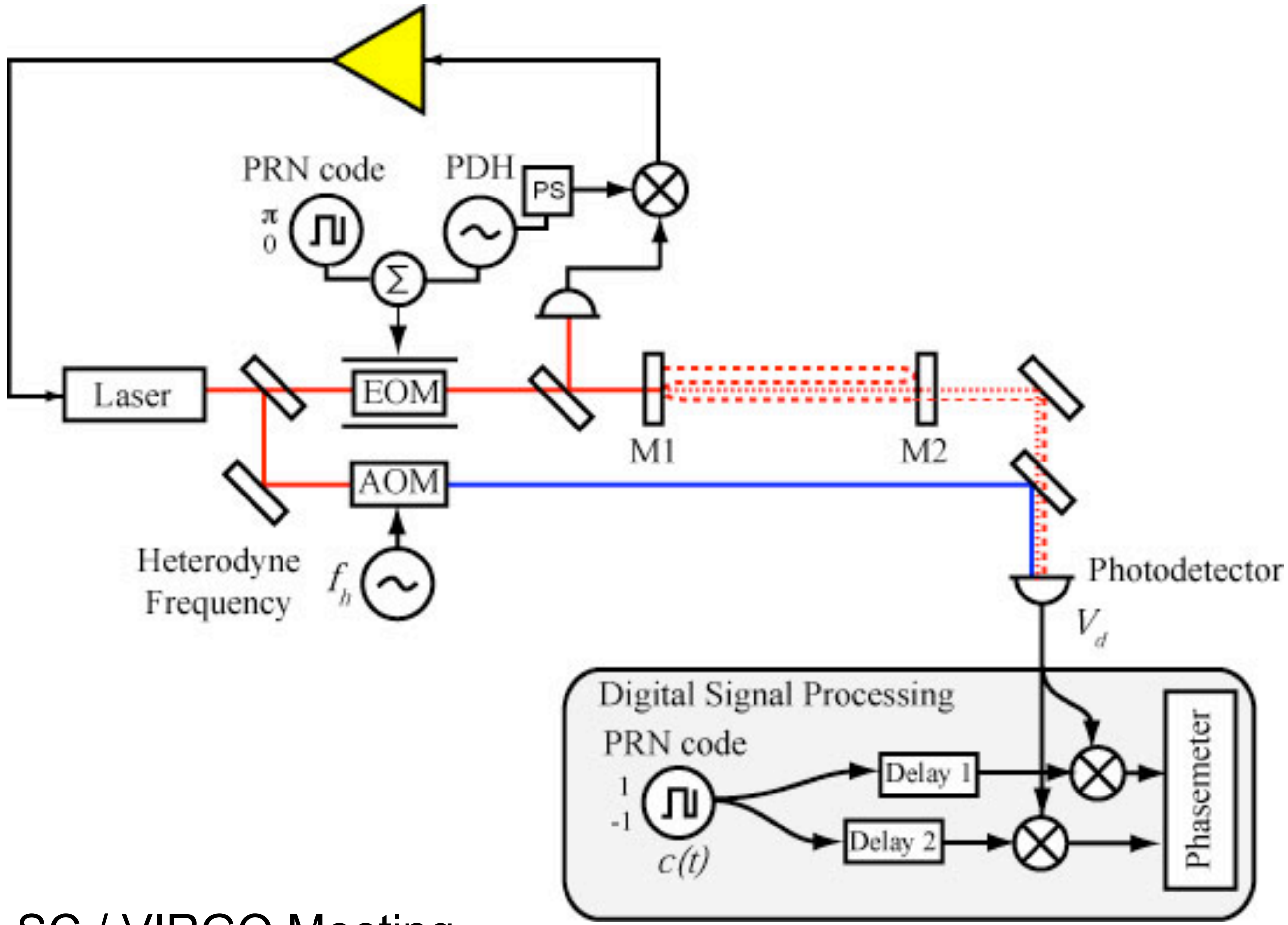


Individual Mirror positions

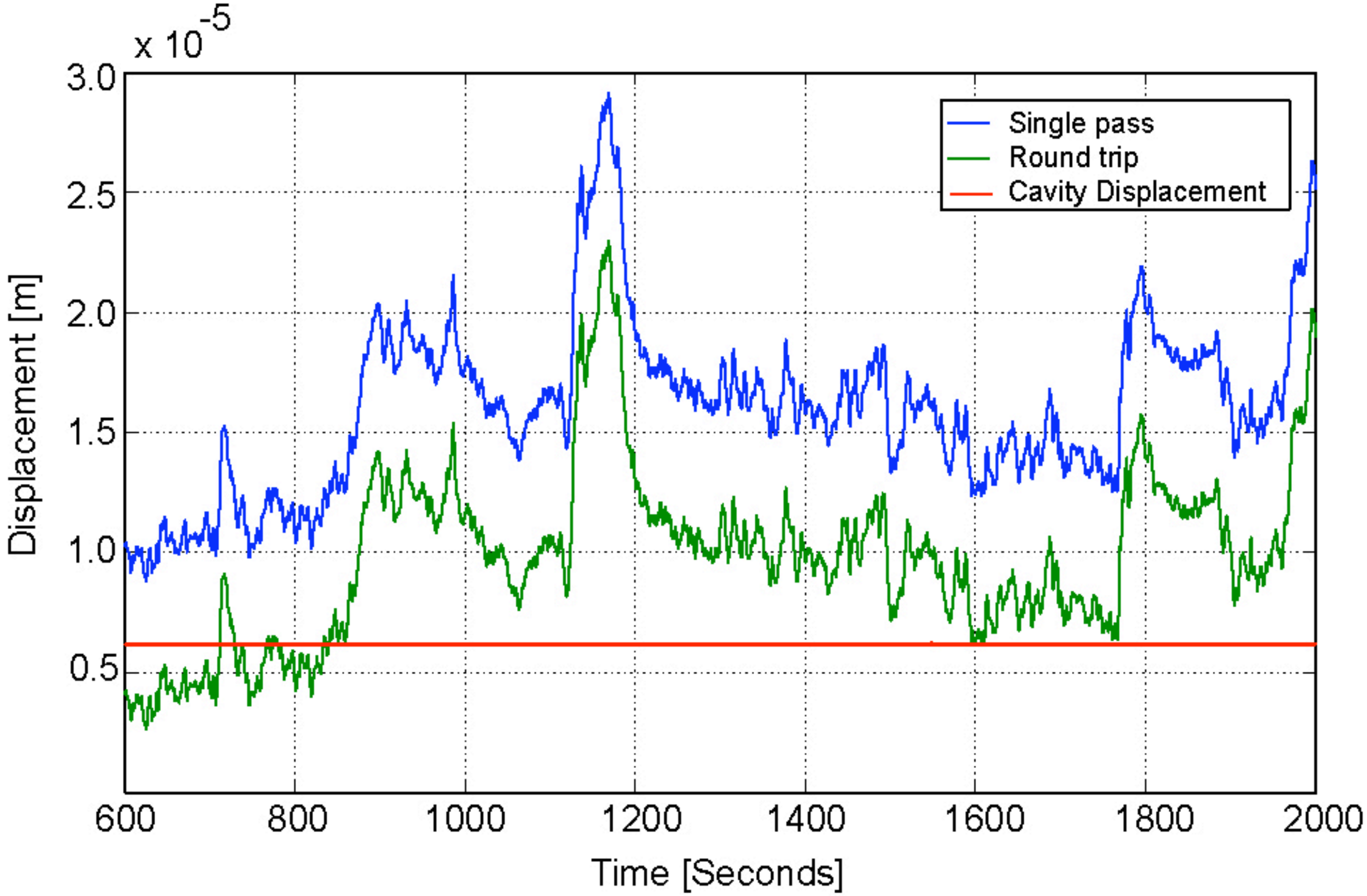


We use for this a real-time decoding and phase readout using FPGA-base signal processing.

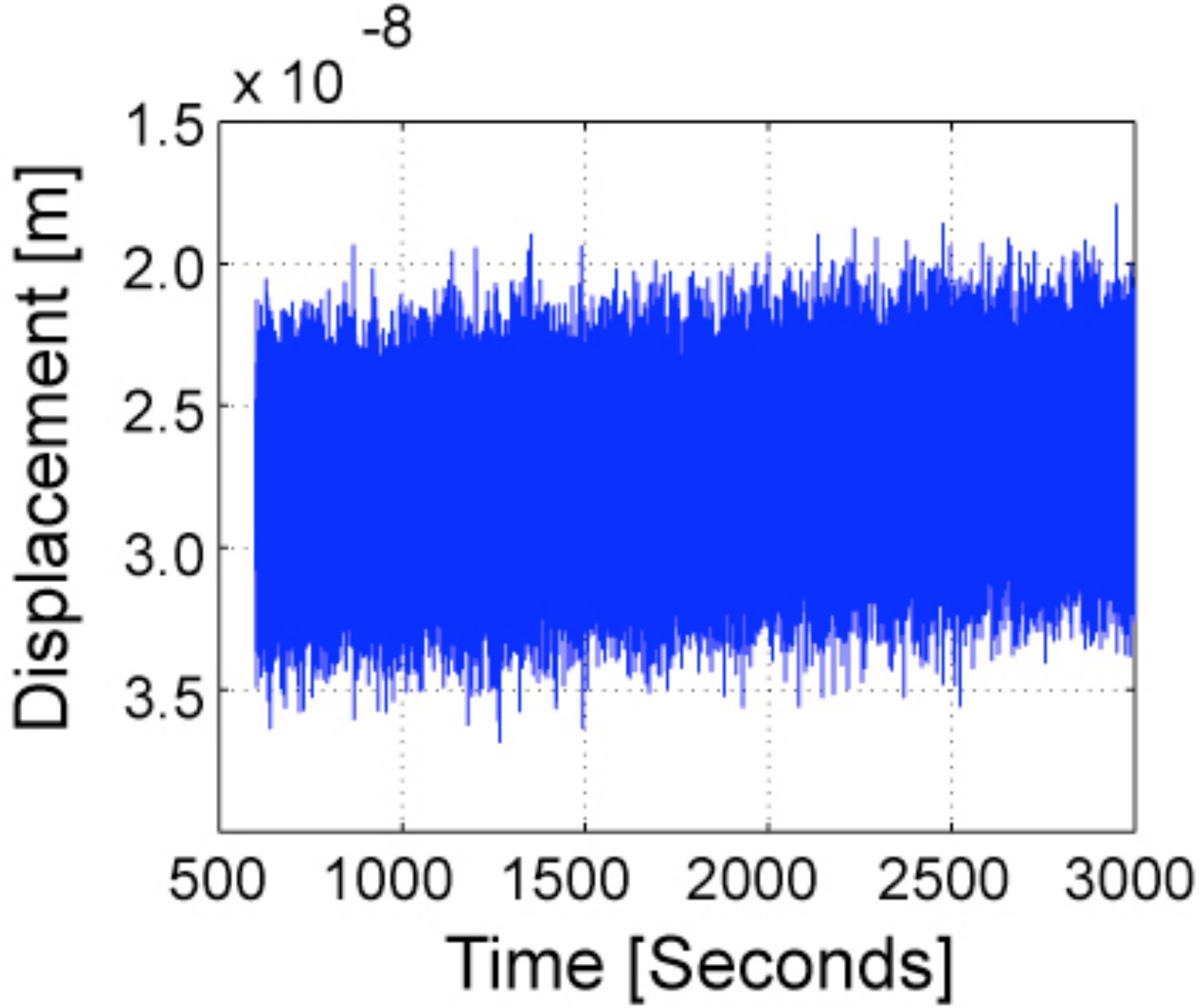
Displacement sensitivity characterized by comparison with Pound-Drever-Hall locking



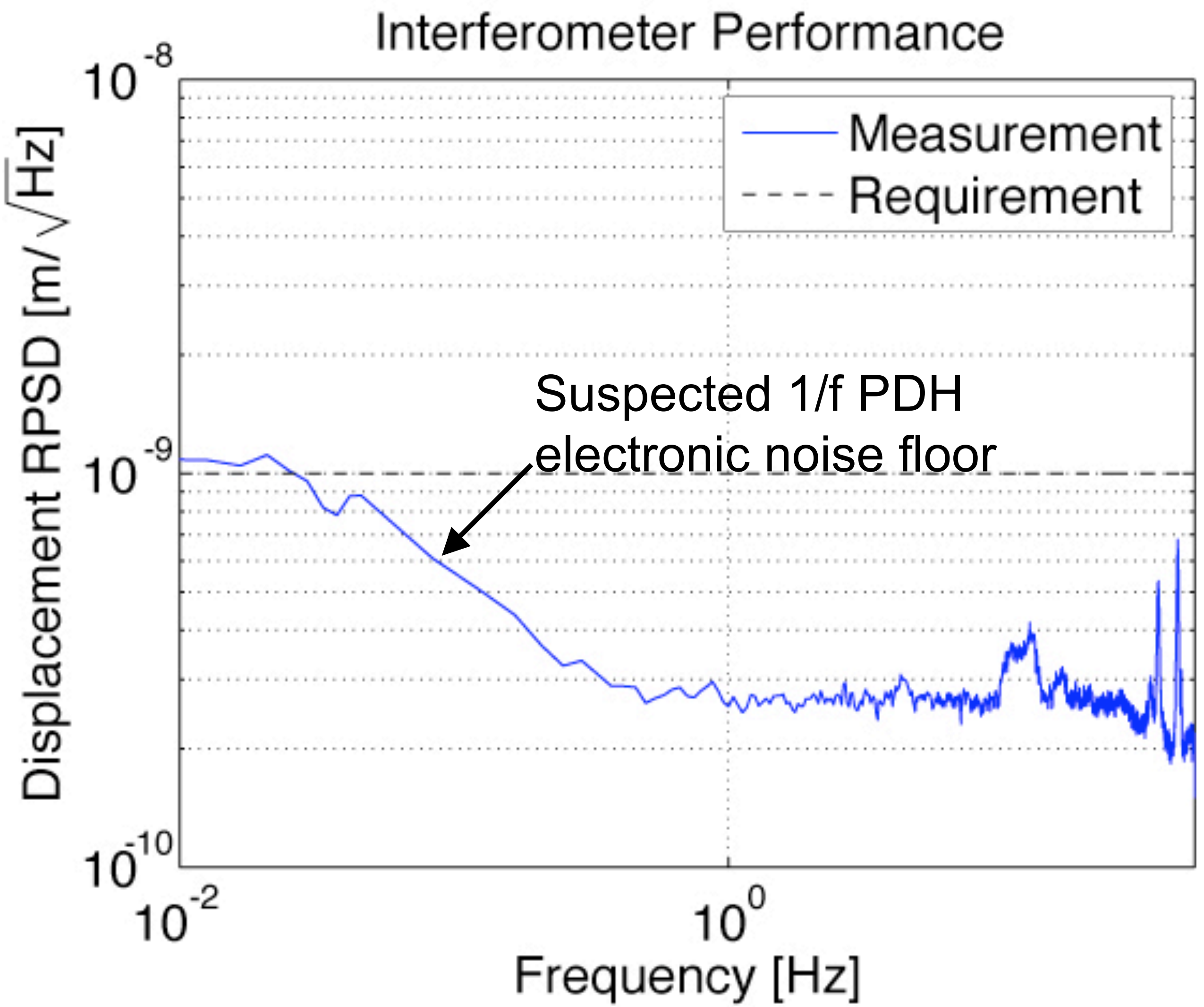
Phase-meter output



Time series - Zoom of cavity displacement



Displacement power spectrum (10^{-2} - 10Hz)



THE AUSTRALIAN NATIONAL UNIVERSITY

Conclusion and further work

We have demonstrated a novel technique to control a multi-element interferometer. By combining standard heterodyne interferometry with digital modulation and demodulation we were able to continuously monitor individual optical components with low cross coupling. By comparing the technique to a well known stabilisation technique we demonstrated the performance to 1nm between 10^{-2} and 10 Hz.

Future experimental tasks will be to optimise code modulation, demodulation and averaging. For AdvLIGO the need to investigate the coupling of the PRN measurement into the main GW measurement and vice versa.