Length sensing and control of the Caltech 40m prototype

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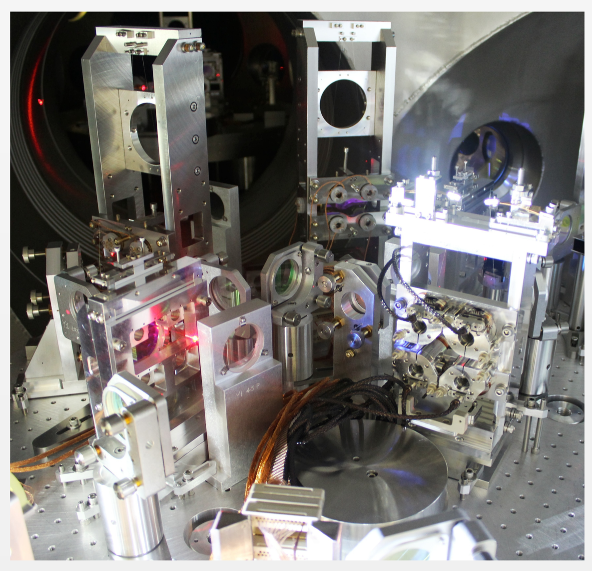
Abstract

The Caltech 40m laser interferometer is the control prototype of the Advanced LIGO (aLIGO) interferometers. The current missions of the 40m are to prototype the optical configuration and controls of aLIGO and to develop interferometer diagnostic techniques. This poster describes the features of the length sensing and control (LSC) system that is designed to realize the longitudinal feedback control of the dual-recycled Fabry-Perot Michelson interferometer.

Optical configuration of the 40m prototype

Dual recycled Michelson with Fabry-Perot arms

- Dichroic ITM/ETM for Arm Length Stabilization using 532nm beams
  - Mimicking aLIGO finesse : ~450 for 1064nm, ~100 for 532nm
- Small Schnupp asymmetry: Δl = ~3cm
  - Similar to the aLIGO's design of 5cm (or currently 8cm [1])
  - Adjusted such that the 55MHz sidebands reach the dark port
- Longer power and signal recycling cavities (PRC, SRC)
  - PRC=6.8m, SRC=5.4m, folded by ANU Tip-Tilt suspensions [2]
- Smaller test masses with SOS suspensions
  - 3 inch dia. x 1 inch thick fused silica mirrors
  - Same DC radiation pressure effect as that of aLIGO



Features in the sensing & control system

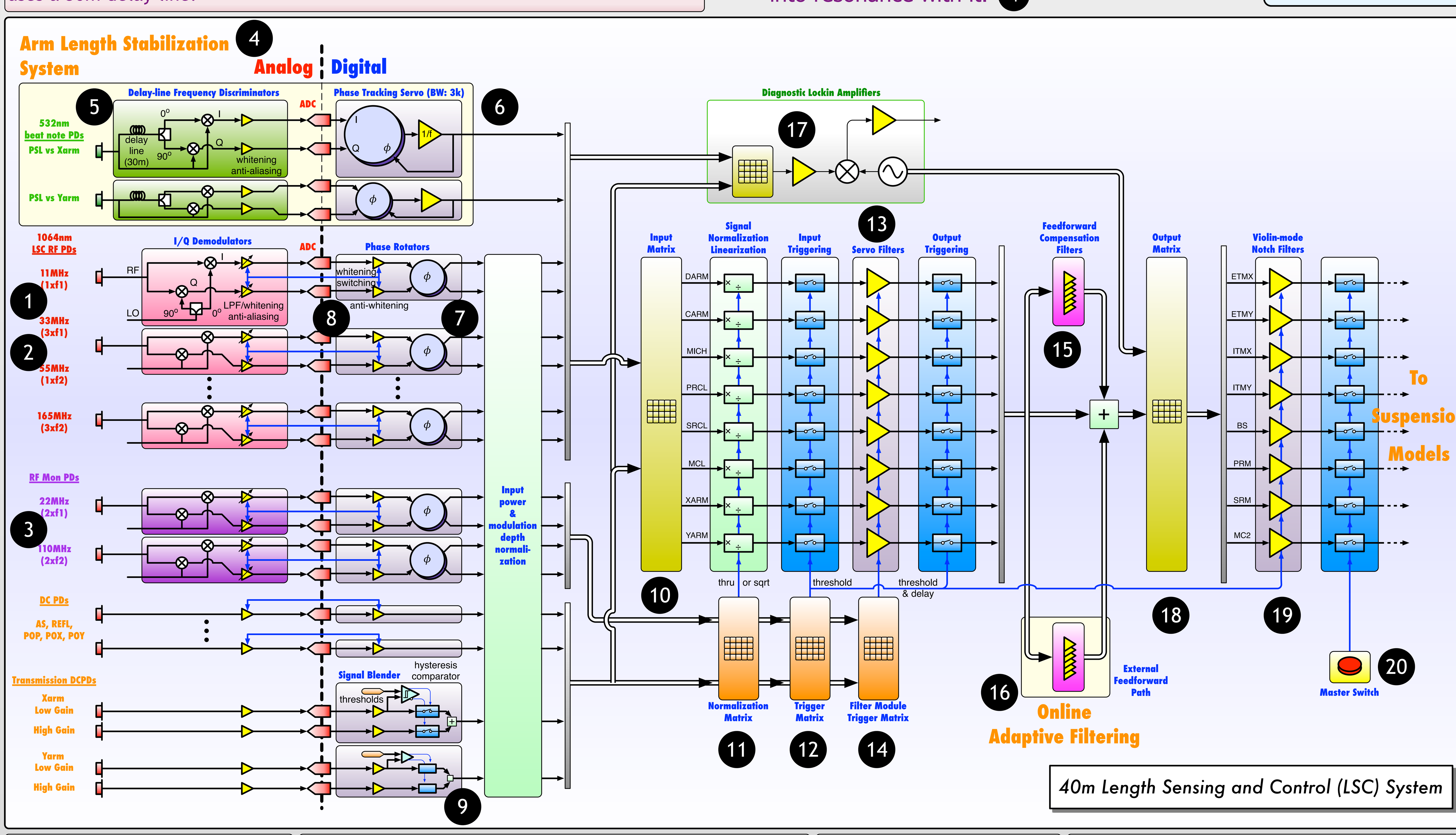
(6) Phase tracking servo: DFD (see 5) has a trade-off between the sensitivity and linear range depending on the length of the delay line. This is solved by using a digital servo loop called "phase tracker". Mixing angle of the I and Q signals are changed by a phase rotation matrix (see 7) such that the output signal always stays at a zero crossing. Linear signal to the fluctuation of the beat note frequency is obtained from the control signal of the servo loop.

(5) Delay-line Frequency Discriminator (DFD): DFD measures the frequency of the beat note signal from the beat PD. The RF beat note signal is mixed with a delayed version of itself in order to obtain a linear signal to the beat frequency. Use of a hybrid splitter let us obtain two independent outputs that enables the linear frequency detection in a wide frequency range (see 6). The current setup uses a 30m delay line.

(7) Digital demod phase rotator: The demod phase of the error signals is rotated by a 2x2 matrix. Non-orthogonality of the analog I/Q signals are also compensated by this.

(8) Automatic whitening filter switching: After a degree of freedom's trigger has been engaged (see 12), the RF PD(s) used (see 10) automatically have their analog whitening and digital anti-whitening turned on.

(9) Signal blender for transmission PDs: High gain PDs are used when light level is low, while low gain PDs are used when light levels are high (e.g. when power recycling cavity is locked). Power threshold comparators determine which signal is used.



(20) Master switch: Enable or disable all length controls.

(19) Violin mode notch filters: These notch filters have been moved from the suspension models to the LSC model so all length degrees of freedom see the same set of filters. When an optic is used for control, all optics being used have a notch filter engaged at that optic's violin mode resonance frequency. As with 14, wait for a trigger to be engaged (power buildup in the cavity is large) for some time before turning on high-Q notch filters.

(18) Output matrix: Select which optic(s) are used to control a given degree of freedom.

(17) Lockin amplifiers: Lock-in amps are used to measure the length sensing matrix. A digital oscillation signal is used to shake a length degree of freedom, and to demodulate the response sensed in each RF PD signal.

(16) Online Adaptive Filtering: Auxiliary system used for tests of advanced control techniques.

(10) Input matrix: RF PD signals are selected and mixed for use to control each length degree of freedom.

(11) Normalization matrix: Intracavity power monitoring signals are selected for use in normalizing length error signals. This normalization increases the linear range of the error signals during lock acquisition.

(12) Length degree of freedom triggering: To avoid unneccessarily applying force to optics (thus causing optics to move more, which increases difficulty of lock acquisition), only allow error and control signals to pass if within linear range of error signal. Power buildup in a cavity (signal selected by a matrix) is used as a proxy to determine linear range.

(13) Servo filter modules: Control filters for each length degree of freedom. Each servo filter has ten IIR filter banks that can be manually or automatically enabled (see 14).

(14) Servo filter module triggering: Utilize triggering capability to engage boosts in length servos, after a cavity is locked. To determine lock, wait for a trigger to be engaged (power buildup in the cavity is large) continuously for some time on the order of 1 sec before engaging boosts.

(15) Feedforward cancellation path: Auxiliary length degrees of freedom (ex. MICH, PRCL, SRCL) can couple to and contaminate the DARM signal. Feedforward compensation is used to remove this coupling.

Interferometer path length sensing

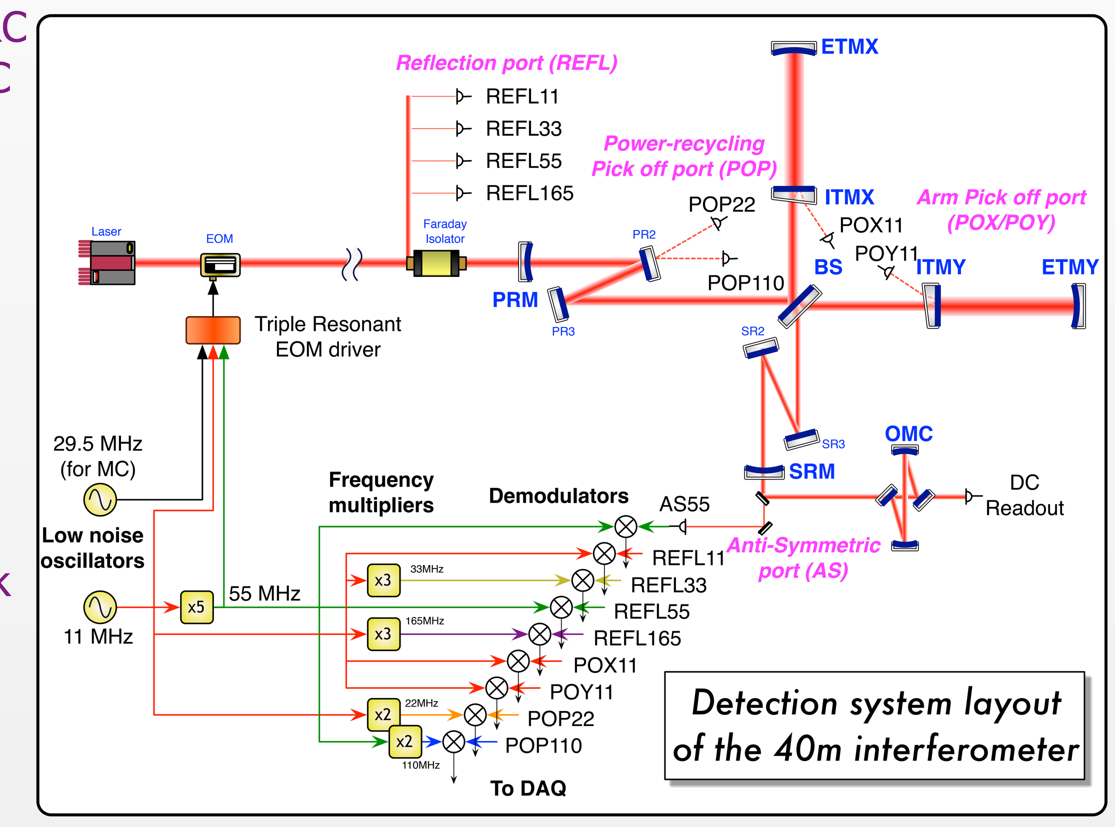
Two modulations and demodulations at harmonic frequencies

- 11MHz and 55MHz modulation sidebands

The 11MHz sidebands resonate in the PRC while the 55MHz ones do in both the PRC and SRC. This difference enables us to separate the PRC, SRC, and Michelson length signals [3].

- Harmonic demodulation

In addition to the demodulation at the above modulation frequencies (1), demodulations at the 2nd (2f) and 3rd (3f) harmonic frequencies are used. The 3f signals are useful in the initial lock acquisition stages due to their inherent insensitivity to the arm motions [4]. (2) The 2f signals are used for the sideband power monitors in the PRC and SRC. (3)

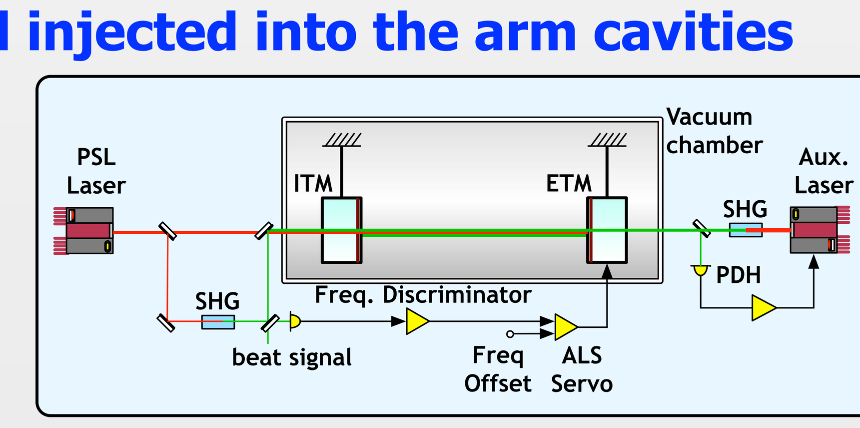


Detection system layout of the 40m interferometer

Arm length stabilization with auxiliary beam injection [5][6]

- 532nm beams are generated and injected into the arm cavities

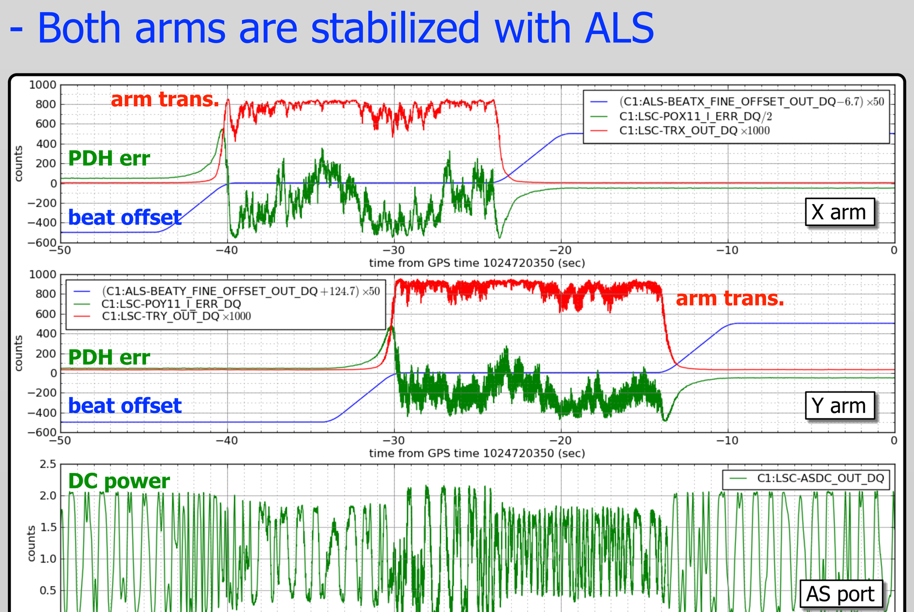
The beat note between the 532nm beams from the aux lasers and the PSL contains information about the arm cavity length fluctuations. This allows the feedback control system to stabilize the arm cavity lengths with respect to the PSL frequency even before they are actually brought into resonance with it. (4)



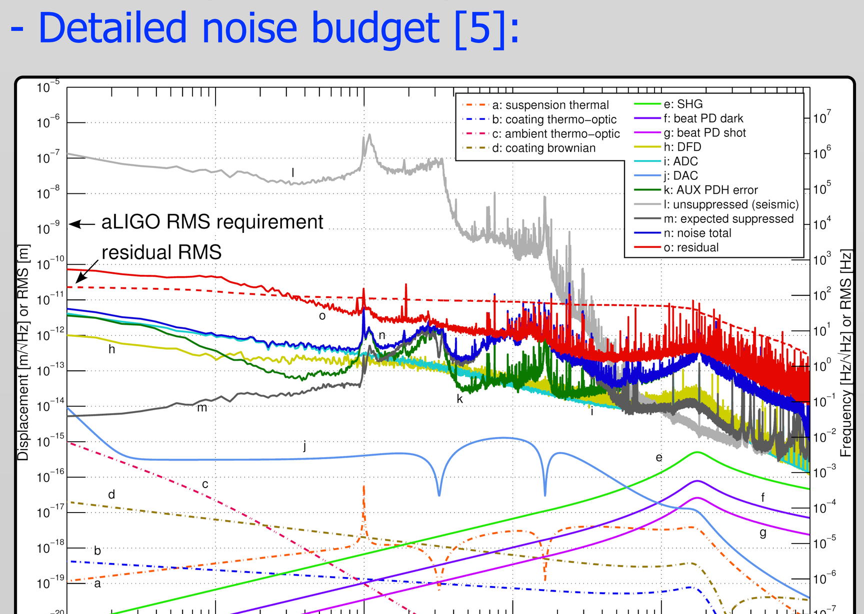
Achievements

Arm Length Stabilization

- Both arms are stabilized with ALS



- Residual motion sensed by the main laser: Xarm 25pm, Yarm 80pm
- Detailed noise budget [5]:



Dual Recycled Michelson (DRMI)

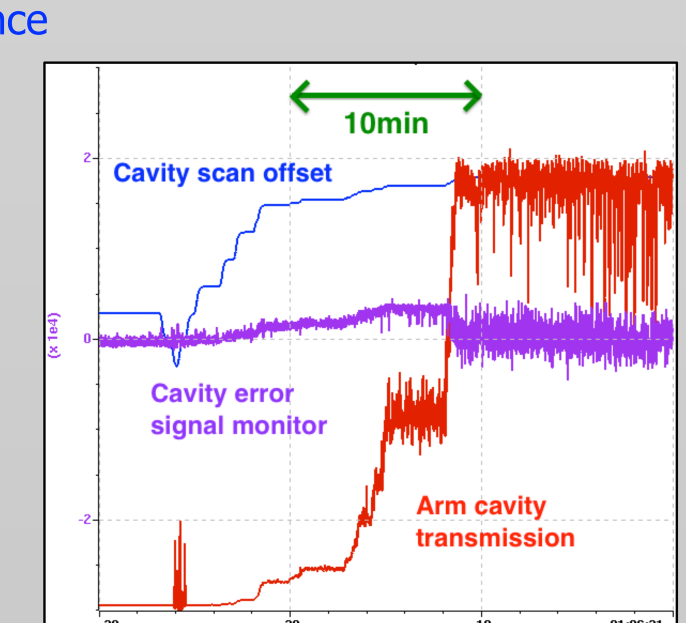
- Control signals:
  - PRCL: REFL11I (1f)
  - MICH: REFL55Q (1f)
  - SRCL: REFL55I (1f)
- Trigger signals:
  - POP22 (2f) for the servo and filter module triggering

Power Recycled Michelson (PRMI)

- Control signals
  - PRCL: REFL165I (3f)/ MICH: REFL165Q (3f)
- Trigger signals:
  - POP110 (2f) or POP22 (2f)
  - for the servo and filter module triggering

PRMI+One arm

- Successful quasi-static transition of the Xarm on the resonance
- No significant disturbance by the carrier resonance seen during the scan



Plans

Towards full locking

- Realizing PRFPMI
  - PRMI + two arm scans with ALS
  - Common/differential arm ALS scan
  - Smooth transition from the ALS to IR signals
- Realizing DRFPMI
  - Establishing DRMI lock with the 3f signals
  - ALS arm scans

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