Calibrating LIGO's GW Detectors via Photon Radiation Pressure

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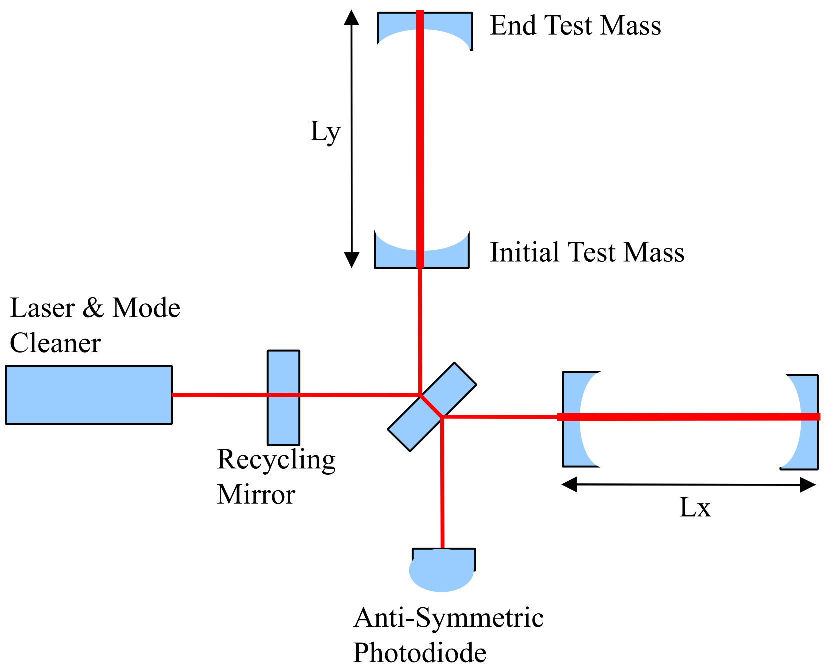
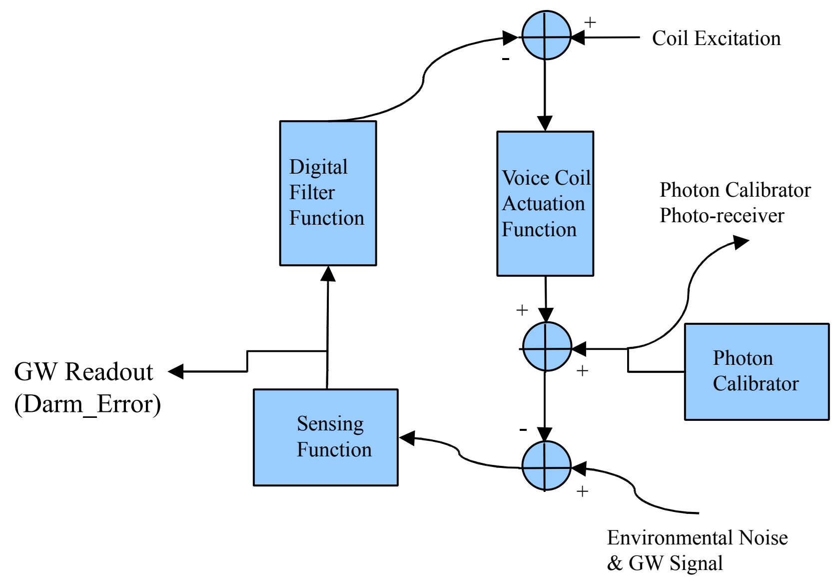
Based on work one by Evan Goetz, Richard Savage, and Matthew West

Response of Interferometer to Differential Arm Motion



Model LIGO interferometer

Closed-loop control of differential arm length



Calibration of GW Readout

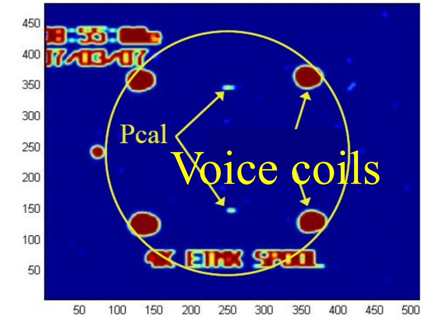
- Error point of Darm servo
  - Counts per meter of arm length difference
- Goal: 10% in amplitude, 10 deg in phase over all frequencies and for all times
  - Required for source localization, waveform reconstruction, etc
- Characterization of Actuation function is a key element
  - expect f^{-2} free mass response to voice coil force
  - Motions on order of 10^{-17} meters

Photon Pressure Calibrator

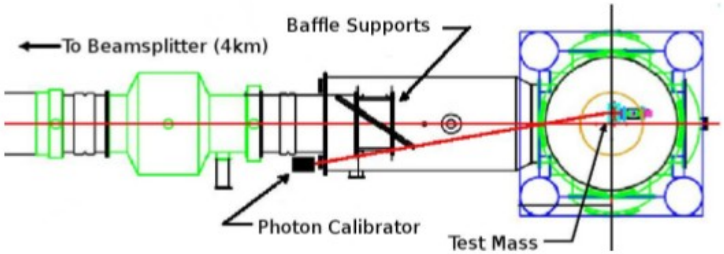
Independent means of generating known displacement

Response of free mass to radiation pressure

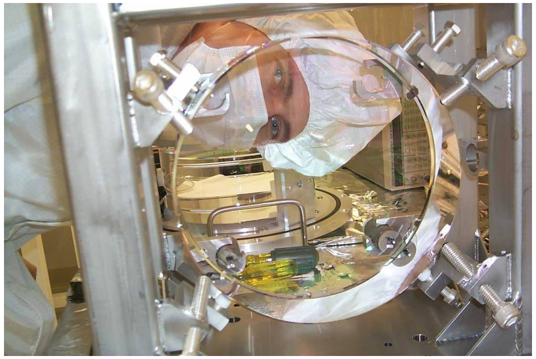
$$x_p = \frac{2P_p cos(\theta)}{Mc\omega^2}$$



Placement of Photon Calibrator outside Vacuum System

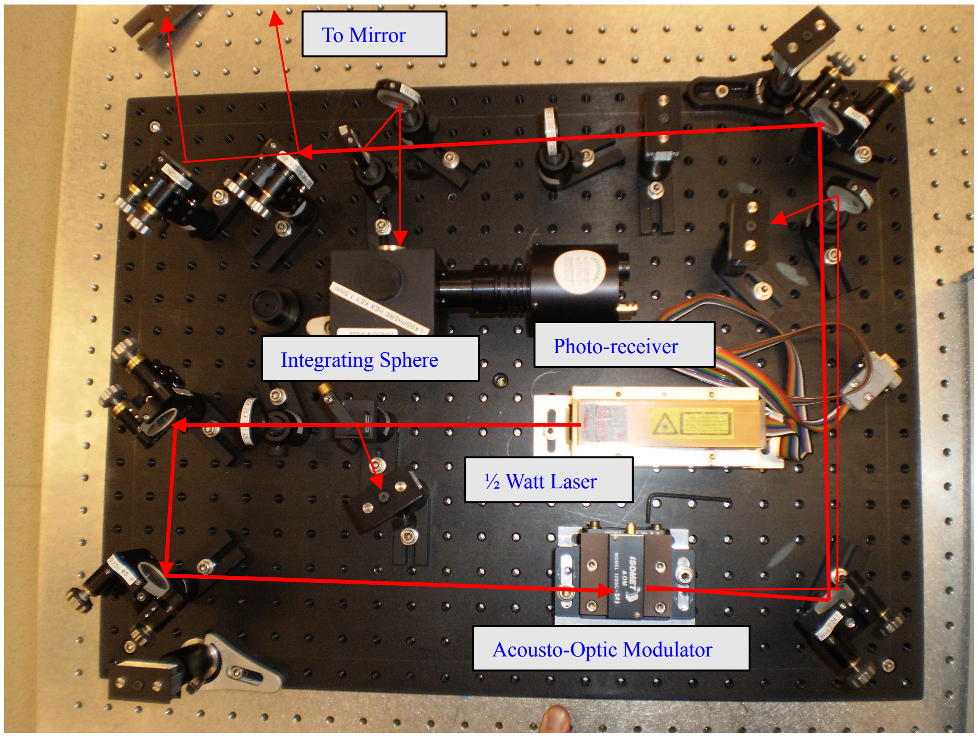


What we are pushing



What I have been building

ELIGO Photon Calibrator



Features

- Integrating Sphere & Photo-receiver
  - Less sensitive to
    - beam pointing
    - temperature variations
- Two beam configuration
  - avoid elastic deformation in center of optic (S. Hild, et al.)
- No electronics in the box
  - reduce heat load
- Calibration of Gold Standard Sphere & Receiver at NIST
  - improved power calibration
- Online actuation coefficient monitor

Measuring the Coil Actuation coefficients A_i

Transfer functions between actuators and Darm_Error

$$\frac{GW\ Readout}{Coil\ Excitation} = \frac{counts\_Darm}{counts\_coil\ Drive}$$

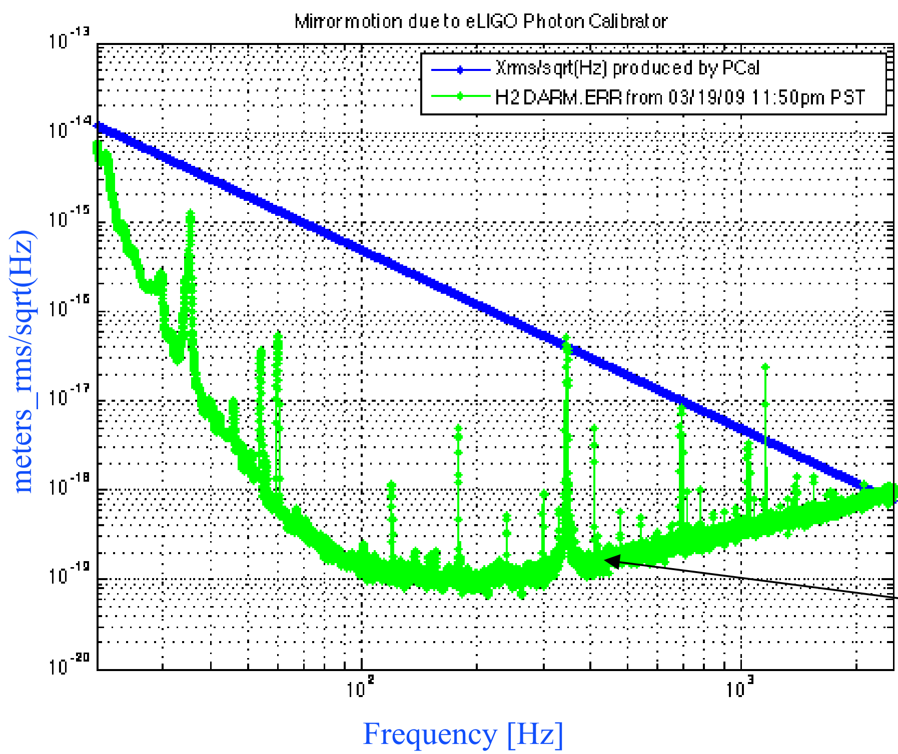
$$\frac{GW\ Readout}{Calibrator\ Power} = \frac{counts\_Darm}{mW\ onto\ Mirror}$$

The ratio of actuation transfer functions

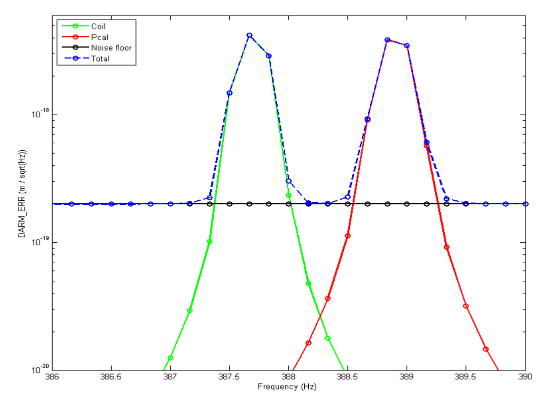
$$\frac{Calibrator\ Power}{Coil\ Excitation} = \frac{mW\ onto\ Mirror}{counts\_coil\ Drive}$$

- Convert monitored power output to mirror displacement using the radiation pressure formula above
  - Calculate meters per count of coil drive
- Photon Calibrator measurements agreed with official calibration of Actuation coefficients for S5 within 10%

The Motion of Mirrors



- M_{mirror} = 10.36kg
- $P_{p\text{-}p}$ = 250mW in total
- Spot Size = 1.7mm
- Beam separation = 15cm
- Freq. separation of Coil and Pcal Lines = 1.2Hz



Plans for eLIGO Science Run

Objectives

- Run Photon Calibrator on one ETM throughout S6 on each interferometer
- Online comparison with coil excitation
- Measure sign of length response function
- Measure Darm loop delay

Goals

- Identify remaining systematic calibration errors
- Measure test mass Actuation function variations over long time intervals with ~2% uncertainty (1-σ)
- More central role for Photon Calibrator in online interferometric calibration

Thanks to Evan Goetz and Richard Savage