Progress towards a Multimode Coating Thermal Noise Experiment

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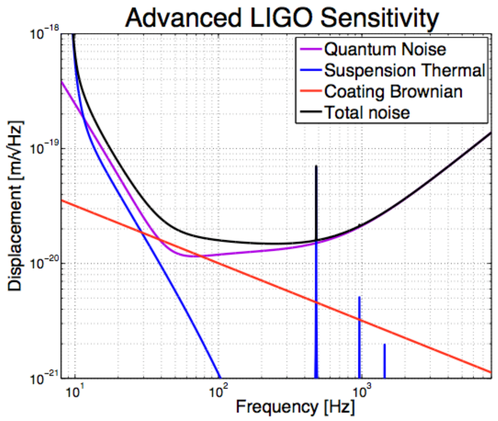
Introduction

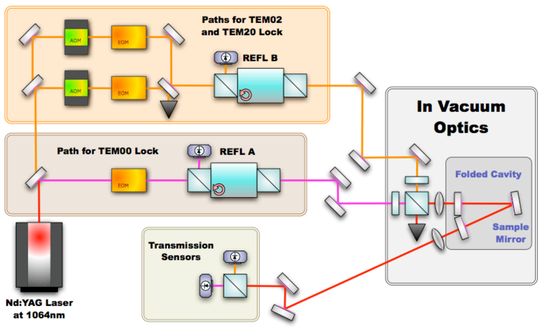
Coating thermal noise is a limiting noise source in the frequency band of interest to aLIGO. Theoretical predictions of coating thermal noise are limited by uncertainties in the properties of the coatings, leading to uncertainty in its predicted effect on aLIGO sensitivity. Therefore, a direct measurement of the thermal noise of aLIGO coatings is needed to assess the validity of the theoretical predictions of coating thermal noise and to guide the development of new coating designs.



Coating thermal noise is a substantial noise source in the LIGO band from ~30-300 Hz

Experimental Setup

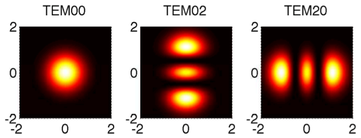
Three resonant fields, TEM00, TEM02, and TEM20, are injected into a single, high finesse folded cavity. 00 is locked in reflection while 02 and 20 are locked in transmission. While they both resonate in the same cavity, the two higher order modes are sensitive to different areas of the sample mirror, giving rise to high common mode rejection while maximizing their differential signal due to thermal fluctuations. The folding mirror acts as the sample mirror.



Optical Parameters:
Input power: 12mW each HOM
HOM mode matching: 12%
Coupling: ~20%
Finesse – 4k, 5k (02, 20)
Cavity Length – 95 mm
Waist size – 61μm
Mode spacing – 225 MHz
02/20 Mode splitting ~ 2 MHz
Radius of curvature – 50 mm

Cartoon of experimental layout. Portions of the optical paths where optical losses are insignificant are fiber coupled to allow for more flexibility

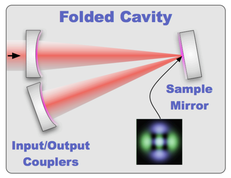
Principle Method of Operation

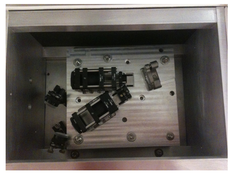


$$N_{coating} \simeq 7.2 \times 10^{-18} \frac{\mathrm{m}}{\sqrt{\mathrm{Hz}}} \cdot \sqrt{\frac{100\,\mathrm{Hz}}{f}} \frac{100\,\mu\mathrm{m}}{w_c}$$

TEM 02 and TEM 20 modes are used to sample different areas of the sample mirror, giving a differential measurement of coating thermal noise on the order of:

Folded Cavity Design





A cartoon of the folded cavity vs. actual cavity inside aluminum enclosure with lid off

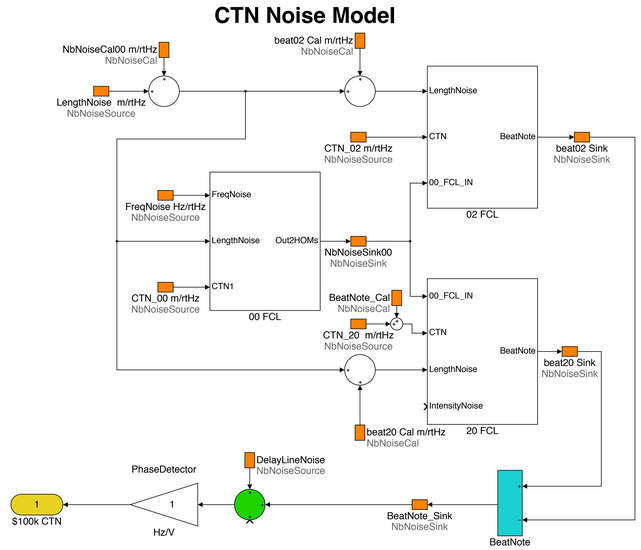
A folded cavity geometry has several advantages over a linear cavity including:

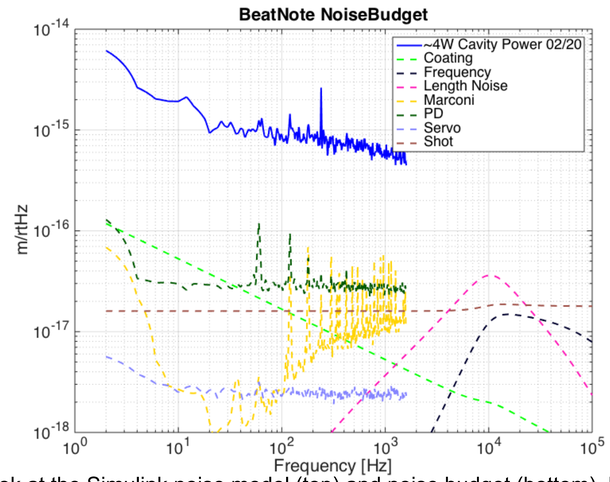
- Only requirement of sample mirror being a flat high reflectivity mirror, allows for measurement of wide range of optics
- Noise contribution of non sample mirrors relative to sample mirror is minimized by keeping the ratio of the beam spot sizes large
- Variable beam size on the sample mirror can be achieved by translating the folding mirror with respect to the waist of the cavity without changing the resonant modes, allowing for the investigation of thermal noise vs. beam spot size
- Polarization splitting of the resonant modes in a folded cavity allows for the exploration of coating thermal noise vs penetration depth due to the different penetration depths of the different polarizations

Current Status of the Experiment

- Cavity is currently set up in air, inside an aluminum enclosure.
- All three modes can be locked simultaneously.
- Beat Note spectra indicate a limiting sensitivity of ~ 10^-15 m/rtHz
- A Noise budget model has been created in Simulink using Chris Wipf's aLIGO noise blocks, and excess noise has been found consistent with a calculation done using Rai's gas noise paper

Noise Budget Model





A look at the Simulink noise model (top) and noise budget (bottom). Note that cavity finesse will be increased to ~50k, which will lower the PD noise by ~10X.

Future Work

- Folded cavity will be moved into vacuum for the next stage of the experiment. Adjustable location of sample mirror will allow for measurement of thermal noise with different beam spot sizes.
- Investigation of coating thermal noise vs penetration depth using polarization splitting
- Investigation of various new coatings including cryogenic coatings can be implemented in the future.