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TNI Design Outline

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This is an internal working note
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1 Introduction

The basic idea of this experiment is to measure the thermal noise spectrum of an optical cavity. In order to minimize the effect of seismic noise and laser frequency noise on our measurement, we will build two test cavities, from which we will extract a differential measurement. We cannot expect the differential measurement to be perfect, however, so we require a certain amount of stability from the beam going into the cavities, and we require a certain amount of seismic isolation of the cavities themselves.

The TNI will consist of two basically independent parts. The first part is the laser stabilization stage, and its job is to deliver a suitable beam to the test cavities. The second part is the test cavity setup itself, which will use that beam to measure the thermal noise in the test cavities. This thermal noise shows up as fluctuations in the length of the cavity, which we will measure by resonating the laser beam in the cavity. The wavelength of the laser light serves as a length standard, so a suitable beam is one that has a stable wavelength.

Fig. 1 shows the basic layout of the TNI.

2 Optical and Control Layout: Laser

It is customary to talk about a laser beam's frequency, rather than its wavelength, so that is the convention we will use from here on. No commercial laser has a stable enough frequency for our purposes, but we can get around this by actively stablilizing the frequency of a good off-the-shelf laser.

This stabilization will be done in two stages. The first stage brings the frequency noise down to something manageable and is essentially a copy of LIGO's Pre-Stabilized Laser (PSL). It is complete as of this writing. The laser is locked to a fixed length reference cavity using three actuators: the slow input on the laser, which tunes the temperature of the laser; the fast input on the laser, which controls a PZT inside the laser itself, adjusting the length of its resonator; and a broad band Pockels cell (BBPC in Fig. 1). The PZT is good from dc up to a few kilo-Hertz, and the Pockels cell provides corrections at higher frequencies. The PZT cannot cover an entire free spectral range of either the laser or the reference cavity, so the temperature of the laser is tuned by the slow input to bring its natural resonance frequency close to that of the reference cavity.

For the final frequency stabilization stage, the pre-stabilized laser will be locked to the mode cleaner. Feedback for this lock will be through two actuators: An Acousto-Optic Modulator (AOM) will provide broadband frequency shifting between the laser and the reference cavity, and the temperature of the reference cavity will be adjusted to match its natural resonance frequency with that of the mode cleaner. The AOM alone will have enough bandwidth to stabilize the PSL stage at all frequencies of interest, but its tuning range cannot cover a full free spectral range of a reasonably sized mode cleaner, hence the need for thermally tuning the reference cavity.

The mode cleaner will be a triangular cavity, with each mirror independently suspended for seismic isolation. This will include some active feedback to damp out motion on resonance. The suspensions for these mirrors will be similar, if not identical, to standard LIGO small optics suspensions. This design was used for the LIGO 12 meter mode cleaner prototype and will probably be adequate for our purposes.

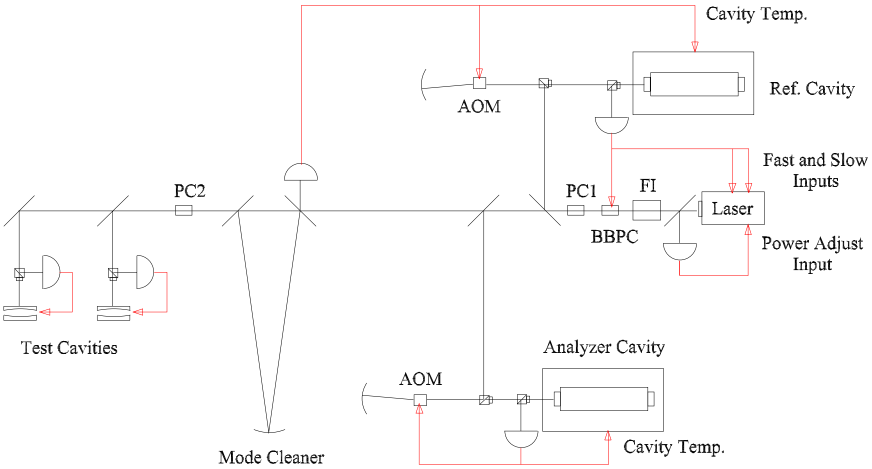

Figure 1: The basic optical and control layout for the TNI. Half-circles are photodetectors; FI stands for Faraday Isolator.

Part of the beam (roughly 10%) will be split off and sent to an analyzer cavity, which will measure frequency noise in the laser. This setup will closely resemble the PSL reference cavity and AOM. However, unlike the PSL cavity, to which the laser is locked, the analyzer cavity will be locked to the laser. The error signal from this lock, combined with the error signal from the frequency stabilization lock, will give upper and lower bounds on the absolute frequency noise in our laser. (The analyzer cavity error signal includes noise in the analyzer cavity itself, giving an upper bound on the laser's frequency noise, while the in-loop laser frequency stabilization error signal gives you a lower bound.) The symmetry of the analyzer and reference cavities allows a great deal of flexibility, which should allow us to unambiguously determine the laser frequency noise. Either cavity can serve as a frequency reference for the PSL stage, with the remaining cavity acting as the analyzer. We can also explore alternate locking schemes, such as locking the laser to the analyzer cavity at low frequencies and measuring the ”free running” noise from the resulting error signal. This setup should also allow us to determine the noise introduced by the AOM.

All of these locks will use the Pound-Drever-Hall technique, and the sidebands for the PSL, analyzer cavity, and mode cleaner will all be provided by a single Pockels cell (PC1 in Fig. 1).

The intensity of the beam will be stabilized by a simple active feedback loop from a photodiode to the Intensity Adjust input on the laser. This photodiode will look at a small part of the beam (again, roughly 10%) tapped directly in front of the laser. It is probably essential to tap the beam for the intensity stabilization loop right in front of the laser. Otherwise, any intensity noise in the beam introduced by the optics would get fed back into the laser. There is significant coupling between frequency and intensity in an NPRO laser, and feeding back intensity fluctuations is likely to introduce frequency noise.

3 Optical and Control Layout: Test Cavities

The test cavities will be locked to the stabilized beam using low frequency servos, with actuators on the mirrors themselves. Standard LIGO small optics OSEM's will likely suffice with little or no modification. The high frequency error signals will provide the data. Residual frequency noise in the laser and seismic noise should give identical signals in both cavities and will be easily rejected.

A second Pockels cell will provide sidebands for the test cavities. (PC2 in Fig. 1) Note that this Pockels cell needs to come after the mode cleaner, so it may introduce some noise into the beam that will not be corrected for by the laser stabilization servos. If this turns out to be a problem, we will have to move this Pockels cell upstream and resonate its sidebands in the mode cleaner. This would be a real pain, and I hope we don't have to do it.

4 Optics: Test Cavities

The test cavities will be short Fabry-Perot cavities. The end mirrors (test masses) will be right cylindars with diameters and thicknesses of 4”. They will have a slight chamfer around the edges and be polished on all surfaces. The intitial test masses will have a radius of curvature of one meter.

We will need surfaces good enough to achieve a finesse of 10^5 and to withstand the high powers we will use. At this writing, I have contacted REO, and they say they can provide mirror grinding, polishing, and coating to meet these specifications. Heraeus has already provided a quotation for the blanks.