LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Estimate of TCS Sensor Requirements

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1 Introduction

This document reports calculations chosen to estimate the required phase sensitivity and position resolution for the TCS sensors. It is assumed here that one sensor interrogates only a single ITM and its associated compensation plate, and that it measures the phase wavefronts on-axis. It is also assumed that the TCS sensor probe wavelength is 632nm.

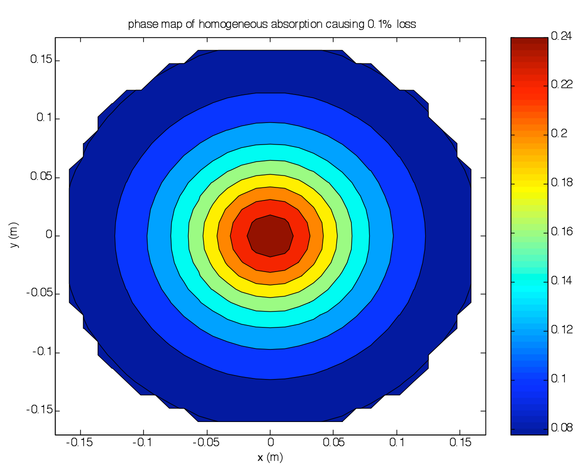
2 Method of the Estimate

The most stringent requirement on the thermal compensation is set by the loss of gravitational wave sideband amplitude to higher order optical modes in the signal recycling cavity due to aberrations. It is estimated that approximately 0.1% of optical loss in the signal cavity will reduce the GW sideband amplitude at the output by approximately 5% at frequencies at and above about 200Hz.[1] Note that this estimate assumes obsolete values for the mirror reflectivities of 95% for the signal recycling mirror and 99.5% for the input test mass.

We calculate the phase variations on the optic for self-heating due to homogeneous coating absorption and due to a single point absorber, and scale the resulting phase maps by an overall factor until the resulting round-trip scatter from the TEM00 mode through the optic is 0.1% of its power. The sensitivity of the TCS sensor is then the sensitivity required to measure these phase maps. This is conservatively assumed to be one-tenth the phase variation over the characteristic length scale of the phase map; that is, a S/N of 10.

2.1 Homogeneous coating absorption

Figure 1 shows the phase map of thermal aberration from homogeneous absorption at a level that scatters 0.1% power from the TEM00 mode. The color levels represent optical phase in radians for a round trip. Taking 6cm as the characteristic length scale of the distortion, the phase variation is .08 radians, and one-tenth of this is .008 radians, referred to the 1064nm interferometer beam wavelength. For 632nm probe wavelength, this corresponds to $\lambda/467$ sensitivity.



[1] Phil Willems, "Detailed Report on Thermal Compensation Effects in Advanced LIGO," LIGO document T040201-00-R, Section 6.

Figure 1: phase map due to homogeneous absorption

2.2 Point coating absorption

Figure 2 shows the phase map for a centralized point absorber that scatters 0.1% power per round trip. This time, the length scale of variation is of order 1cm, although is perhaps limited by the finite resolution of the model, but the scale of phase variation is again about .08 radians. Thus, the sensitivity required is still λ/467, but the required position resolution appears to be roughly 1cm.

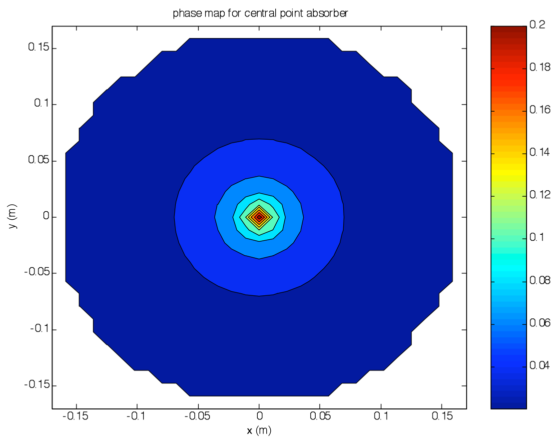


Figure 2: phase map for a point absorber that scatters 0.1% power from the TEM00 mode

Figure 3 shows the same model, but with 2x finer grid spacing on both axes. The feature is not much changed. Finer meshing is not possible with the 3D FEMLAB model used.

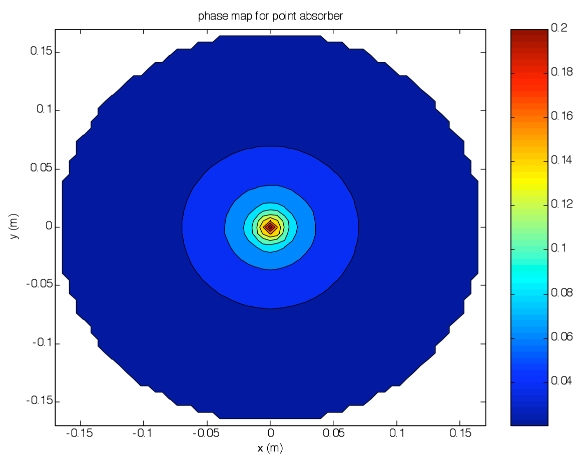


Figure 3: point absorber, viewed with higher resolution

These requirements are rather stringent. A 1cm by 1cm grid on the test mass will require about 1000 pixels, and λ/467 sensitivity is very difficult to achieve with a Hartmann sensor. However, if we relax the phase measurement requirement to a S/N of only 3, then the sensitivity requirement is only λ/150.