LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1400055-v1 *LIGO* February 18, 2014

Core Optics related loss hierarchy of aLIGO

Hiro Yamamoto

Distribution of this document:
LIGO Scientific Collaboration

This is an internal working note
of the LIGO Project.

California Institute of Technology
LIGO Project – MS 100-36
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

1 Introduction

Most of the core optics have been delivered and many of the characteristics of those optics have been measured quantitatively. In this document, the degradation of the aLIGO performance caused by these as-built optics is summarized using a FFT simulation package using measured data of those optics.

The sizes and quantities of most of the optics are properly designed and well fabricated. There are several issues to be noted for the future improvements of the aLIGO performance.

One is the size of the beam splitter. From the loss and field quality in the IFO point of view, the current aperture, 367.1mm aperture and 60mm thickness is not bad. But the horizontal size of the clear aperture, after taking into account the thickness, is not large enough compared to the beam size and the small offset or the vibration of the BS baffle could induce larger contrast defect and noise. It is shown that this problem is reduced by enlarging the BS size to 450mm aperture, 7.35mm thick.

2 Cold state IFO performance – design parameters

The cold state IFO performance was studied using the aLIGO PRMI configuration with arms (Fig.1). All the losses and the curvatures of the power recycling cavities, BS and test masses are taken from the optics summary webpage (https://galaxy.ligo.caltech.edu/optics/) and cavity parameters are from LLO database (E1200274-v3). Only curvatures of test masses are set to the design values, RoC of ITM = 1934m and RoC of ETM = 2245m.

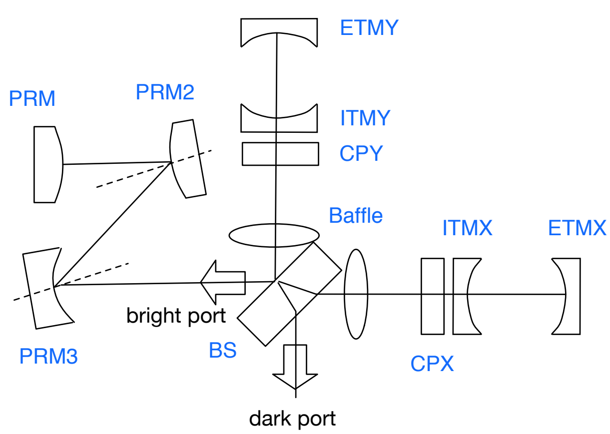

Figure 1 aLIGO PRMI with arm

The round trip loss of the arm is determined by the mirror surface phasemaps. The effects of the difference of the as-polished test mass is discussed together with the effects of the various maps in the following sections. In this section, the round trip loss of 35ppm is assumed for both arms when map effects are studied.

The mode matching of the PRC and the arms are maximized by adjusting the length between PRM2 and PRM3. With the parameters used, the distance is lengthen by 9.33mm for the adjustment of the mode matching. The beam sizes determined this way is appropriate for the discussion around the BS. Mode matching issues will be discussed in separate sections.

In the following figure, three quantities are shown, 1) Power recycling gain, the power at the bright port of the BS, 2) Contrast Defect, the ratio of the power on the dark port of the BS to the power on the bright port, and 3) the total higher order modes in the bright port of the BS.

The horizontal axis corresponds to an IFO setup with different effects included. At various stages, the power recycling gain calculated by the FFT simulation is compared with analytic calculations of a simple 3 mirror coupled cavity with proper transmissions and losses for each stage and they agree each other well as shown by red squares in Fig.2.

The setups of each stage are as follows. Stage 1) corresponds to a perfect lossless IFO with PRM and ITM transmittances of 3.1% and 1.48% each. A stage shown as "N) M) + *additional conditions*" means that the stage N has the same setup as stage M and "*additional conditions*" added to stage M.

1) no loss at all, with large mirrors. A finite HOM (3.7ppm) looks a nice gaussian so probably the base mode parameter is slightly off.
2) 1) + ETM transmittance 3.7ppm
3) 2) + test mass aperture 326mm, round trip loss by the aperture is 1.94ppm (with 340mm, RTL is 0.6ppm)
4) 3) + 266mm ESD aperture, placed using BS baffle (266mmx266mm) in front of BS
5) 4) + 35ppm arm loss
6) 5) + power recycling mirror and beam splitter loss and transmission. Sum of losses + RM2 transmission is 583ppm
7) 5) + ITM AR side loss, (ITMX loss 206ppm, ITMY loss 330ppm)
8) 5) + 6) and 7), i.e., losses and transmission in the PRC, BS and ITM AR
9) 8) + finite opening angles in PRC (0.79° for PRM2 and 0.615° for PRM3). Among the total HOM of 240ppm, major ones are HG(1,0) of 12ppm and HG(0,2) of 210ppm.
10) 9) + PRM3 aperture 262mm
11) 10) + BS 367.1mm/60mm no baffle
12) 11) + BS baffle (210mmx260mm). Total HOM goes up to 540ppm from 260ppm by clipping using BF baffle. The major is HG(4,0) of 170ppm.
13) 12) with BS baffle facing to X arm offset by *1mm* in horizontal direction
14) 12) with BS baffle facing to X arm offset by *2mm* in horizontal direction
15) 10) + BS 410mm/67mm with BS baffle (237mmx260mm)
16) 15) with BS baffle facing to X arm offset by *2mm* in horizontal direction
17) 10) + BS 450mm/73.5mm with BS baffle (260mmx260mm) : no performance impact by the BS baffle
18) 17) with BS baffle facing to X arm offset by *2mm* in horizontal direction
19) 10) + BS 490mm/80mm with BS baffle (260mmx260mm)
20) 19) with BS baffle facing to X arm offset by *2mm* in horizontal direction

As can be seen from the PRG plot, the power gain is not limited by the BS size. Main issue is the sensitivity of the dark port power on the BS baffle, which is placed to reduce the contrast defect (T1000090). Small offset of the BS baffle can increase the CD, and its vibration can induce noise. Fair amount of the tail is clipped by the BS baffle, and the higher order mode fraction is doubled.

With larger BS size, the PRG does not recover much compared to the current design (ϕ=37cm/d=6cm), 63.4 to 65.9, but the sensitivity to the BS baffle offset is much suppressed and the higher order mode goes down to the minimal level cased by the finite opening angles in the PRC.

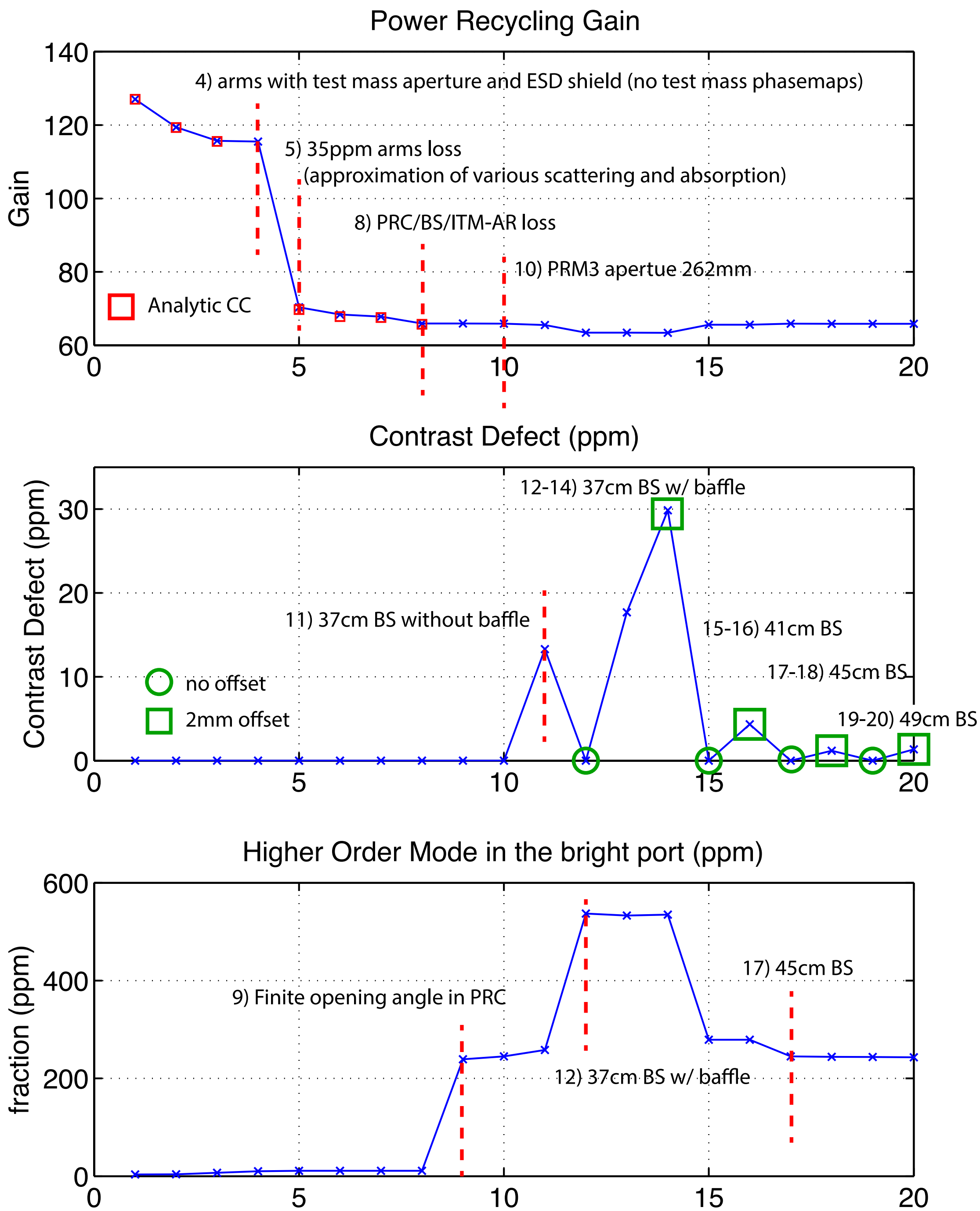

Figure 2 Effects of Optics on IFO properties
Horizontal axis is the different stage of optics effects included (See text)

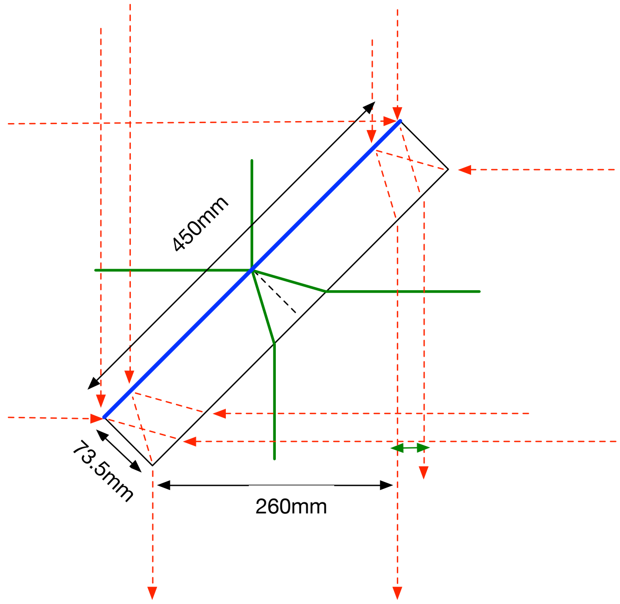

Figure 3 BS geometry and clear aperture

The optimal size of the BS will be around 45cm. As above figure shows, the smallest clear aperture size is 26cm, which is the intrinsic size of the beam coming from PRM3 and from ITM with ESD. Because of minimal beam clipping due to the BS, the higher order mode does not increase by the size of the BS as is shown Fig.2.

3 Cold state IFO performance – effects of non-uniform maps

4 Thermal effects on the interferometer performance

5 Reference