LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1301001-v1 *LIGO* December 15, 2013

Modeling LLO PRMI using FFT simulation package, FOGPrime13

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1 Introduction

With the optical quantities, the performance of the PRMI at LLO was analyzed using FFT-based simulation package FOGPrime13.

Without FP arms, the resonating fields are strongly effected by the ITM substrate non uniformity. By changing the RoC of ITMX, simulating the effect of the ring heater of TCS, the recycling gain was estimated to be 40 and the contrast defect to be 1400ppm with the RoC of ITMX changed by -34m to match with the effective RoC of ITMY seen from the PRC. This includes the ITM maps and BS maps calculated using the normal incident beam measurements.

With the same parameters, the PRMI with two FP arms was analyzed. The round trip loss of the X arm is 37ppm, and that of Y arm is 40ppm. This is much better than the original estimation or budget assignment of, 70ppm per arm. Two arms are well balanced as is, and the performance was the best without any RoC changes. With the BS02 maps, the recycling gain comes out to be 64 and the contrast defect to be 280ppm. Without the BS02 maps, or for the case using better BS, the contrast defect comes down to be 100ppm with same recycling gain. If additional 5ppm/mirror is assumed for all test masses, the recycling gain comes down to be 57.

Also discussed in this document is the effect of the ring heater for the PRMI without arms. The dependence on the RoC(ITMX) change by the ring heater is best described by the imbalance of the beam covertures reflected by the ITMX and ITMY.

Beam profiles around the BS is discussed in details to understand the effect of the physical size of the BS. It is shown that the loss on BS by itself is a very confusing quantity because the beam size on BS is strongly affected by mirrors and baffles.

In this document, the effect of the ring heater is simulated by changing the HR side RoC. The magnitude of the change is defined as

$$\frac{1}{RoC_{corrected}} = \frac{1}{RoC_{cold}} + \Delta$$

or

$$RoC_{corrected} - RoC_{cold} = -RoC_{cold}{}^{2} \cdot \Delta$$

2 PRMI with arms

The distance between PRM2 and PRM3 is adjusted to make the PRC mode to match with the mode of the arm using the cold state optical parameters, without any substrate quantities included. Then the input beam mode is set to match with the mode defined this way. I.e., the mode of the input beam matches with the idealistic cold state cavity.

Fig.1 shows the recycling gain / contrast defect vs the RoC correction of two ITMs. In these plots, values of 1^{-5} (1/m) corresponds to the change of RoC by -34.7m, which is optimal for ITMX correction when there is no arms attached.

Left surface plots are the values as a function of Δ_{RoCX} and Δ_{RoCY}, and the right plots are same quantities as a function of Δ_{RoCX} - Δ_{RoCY}. These plots show that the performance is good when

$\Delta_{RoCX} \sim \Delta_{RoCY}$ and $\Delta_{RoC} \sim 0$. If the input beam mode is chosen to be different from the cold state optimal mode to be experimentally optimal mode, the optimal Δ_{RoC} can be different.

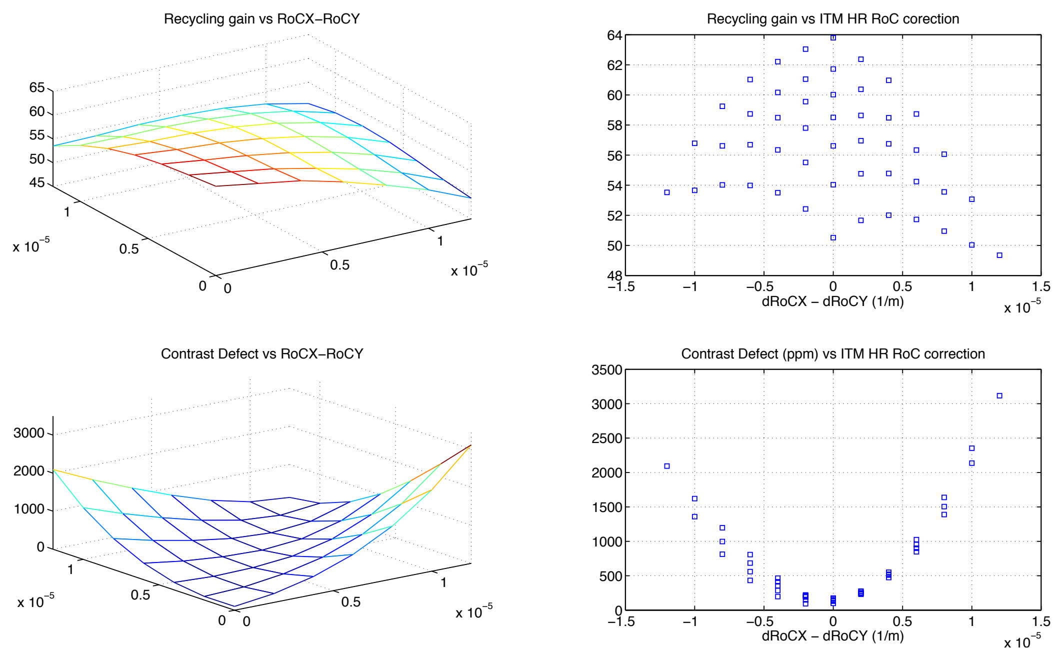


Fig.1 Recycling gain and Contrast Defect vs ITMX and ITMY RoC correction

3 PRMI without arm

Fig. 2 plots the recycling gain and contrast defect vs the RoC correction of ITMX. They show three cases, with BS02 maps and BS baffles (blue line), only with BS baffles (or better BS), and no maps and no baffles. The bottom plot shows the RoC of fields on the BS, one coming from the X arm and other from Y arm. As is discussed later, the beam sizes of these two fields are identical because of the near field propagation, but the RoC of these fields can be different. By comparing these plots, it is observed that the optimal RoC correction of ITMX is that the RoCs of the two fields merging on BS are close.

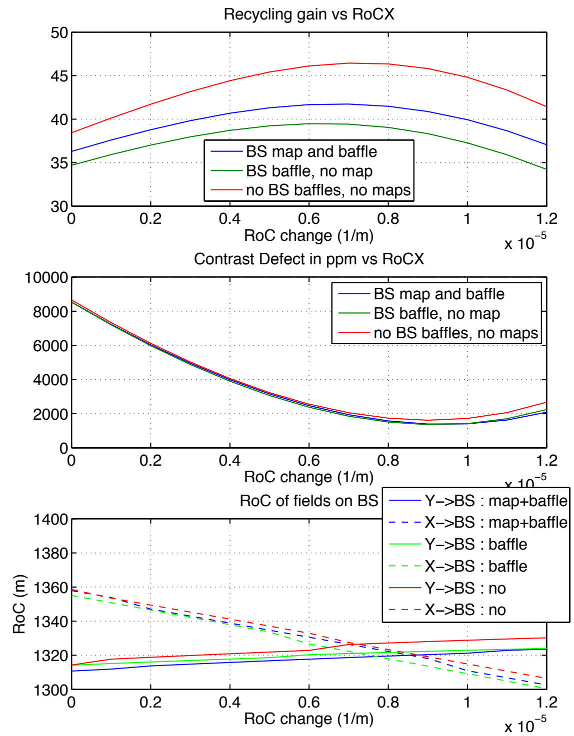


Fig.2 Recycling gain and contrast defect vs ITMX RoC

4 Details around BS

Beam propagations between PR3, BS and two ITMs are all near field propagation, that means, power distributions stay the same, except by the explicit cut by the BS clear apertures and the BS baffle. The beam from PR3 hits the BS, and partially transmits to X arm and to Y arm. These fields have the same beam width and field wave front. On reflection by ITMX and ITMY, the beam size stay the same, but the RoCs can be different because of the difference of ITMX and ITMY. So, back on BS, the beams from X and Y directions have the same beam widths, but the RoCs can be different. Because of that, the contrast defect and dark conditions are more directly related to the RoC of the fields, rather than the beam width.

The beams from X and Y arms merge on the BS, and goes together to PRC. So, the effect of the ITMX and ITMY are mixed together to form a resonant state in a cavity defined by PRC, ITMX and ITMY. In the first plot in Fig.3, the beam width in the horizontal plane and in the vertical plane are shown. These values are common for all fields around the BS, to PR3, to ITMX and to ITMY.

5 Loss around BS

Loss round BS is a mess. Long discussion will be added.

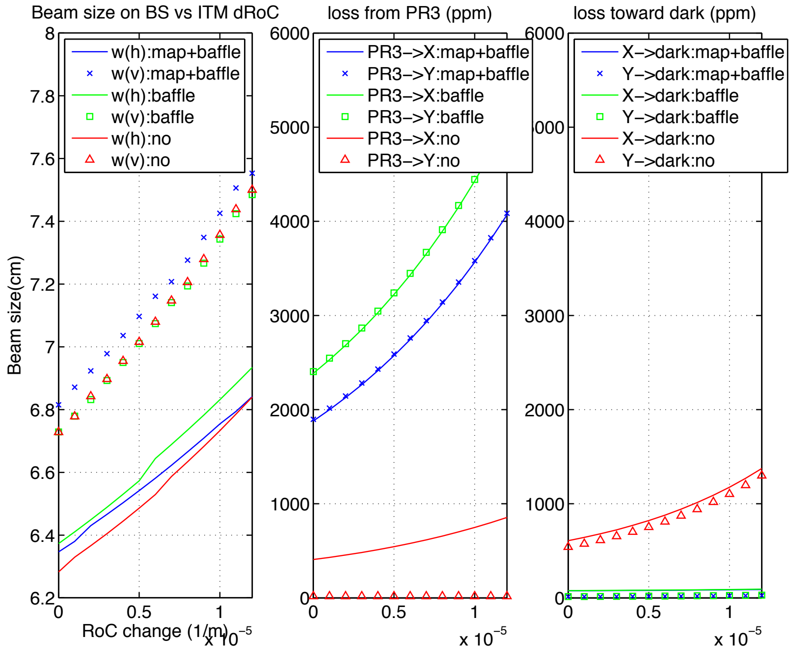
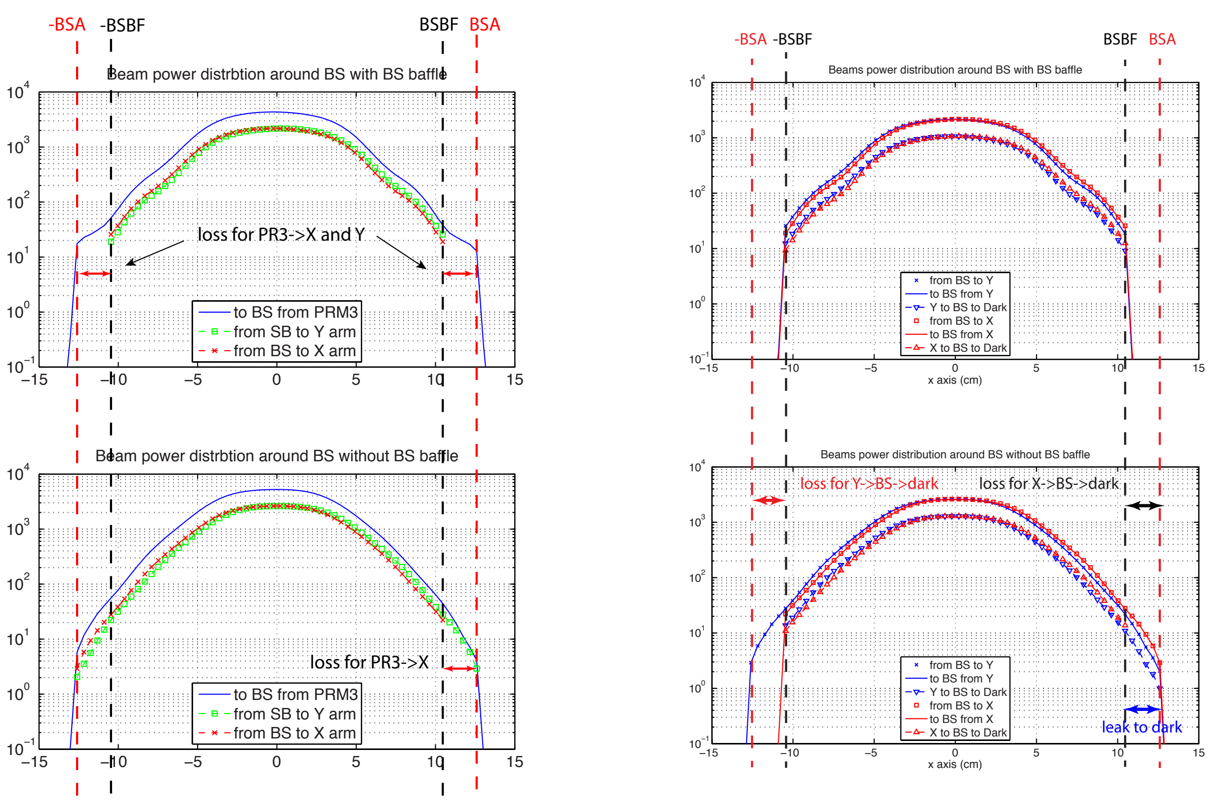


Fig.3 Beam and the loss vs ITMX RoC correction



6 Reference

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