LIGO Laboratory / LIGO Scientific Collaboration

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Retro-reflection from the ITM and ETM Flats and Barrel in the Arm Cavity

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Abstract

This note calculates the retro-reflected power into the arm cavity from the flats and barrel surfaces of the COC, for the case in which the AR surface is perpendicular to the barrel axis of the COC. The estimated relative scattered light noise caused by the retro-reflected power is sixteen orders of magnitude lower than the scattered light noise requirement and is negligible.

1 Introduction

This note calculates the retro-reflected power from the flats and barrel surfaces of the COC in the arm cavity, for the case in which the AR surface is perpendicular to the barrel axis of the COC. This light power will inject an out-of-phase field into the arm cavity mode and may cause phase noise, or a varying contrast defect. An estimate is made of the relative scattered light noise.

A plan view of the COC mirror with reflection from the flat on the side of the barrel is shown in Figure 1. The retro-reflection near the horizontal mid-plane is caused by the corner formed between the flats (or the barrel, if there are no flats) and the AR face of the tilted COC.

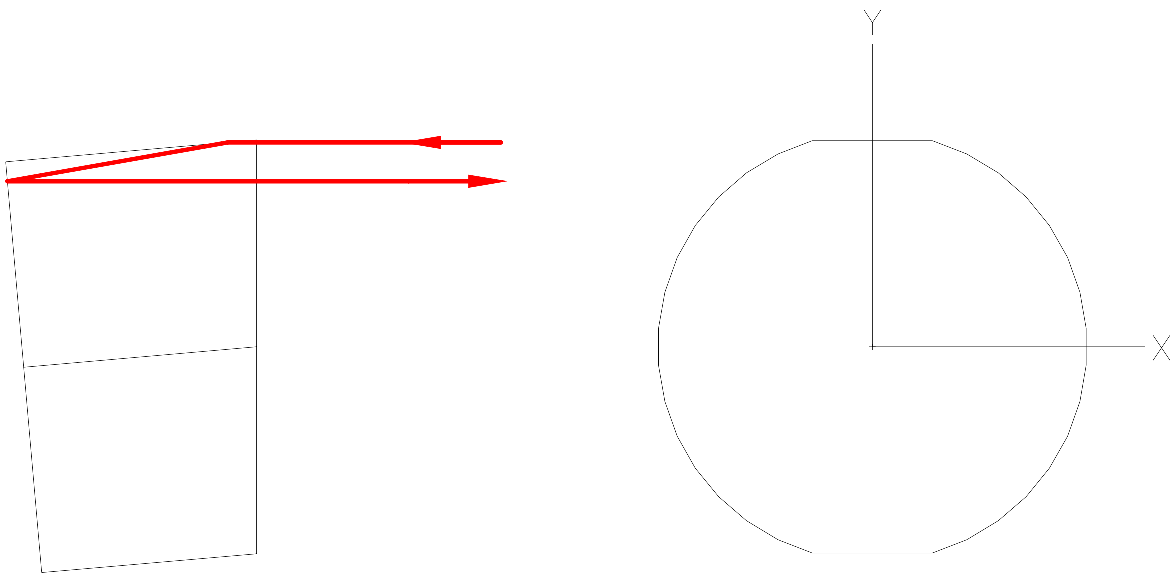

Figure 1: Retroreflection from the flat and the AR face of the COC

1.1 Referenced Documents

- G070482-00 Update on Suspensions for Enhanced and Advanced LIGO, N. Robertson

2 Analysis

2.1 Retro-reflected Power from the Flats

The barrel axes of the ITM and ETM are tilted by the amount of the wedge angles. Rays from the far-end COC will pass through the HR surface, hit the surface of the tilted flat on the barrel of the near-end COC and reflect and hit the AR surface. The ninety degree angle between the flats and the

AR surface will form a retro-reflecting corner that will return the ray back through the HR surface to the far-end COC.

The following parameters were used in the calculation.

transmissivity of HR surface	$T_{HR} := 5 \cdot 10^{-3}$
reflectivity of AR surface	$R_{AR} := 50 \cdot 10^{-6}$
reflectivity of flats and barrel surface	$R_{fb} := 1$
length of barrel and flat, mm	$L := 200$
radius of ITM, mm	$R := 170$
horizontal position of flat, mm	$y_{flat} := 163.2$
vertical height of flat, mm	$x_{flat} := 47.5$
wedge angle of ITM, rad	$\theta_w := 0.08 \cdot \frac{\pi}{180}$ $\quad \theta_w = 1.396 \times 10^{-3}$
Gaussian beam radius, mm	$w := 55$
total integrated beam power, W	$P_T := 1$

The fractional retro-reflected energy was calculated as shown below.

total integrated power hitting the COC, W

$$P_{coc} := P_T \cdot \left(1 - e^{-2 \cdot \frac{R^2}{w^2}}\right)$$

lateral extent of retroreflecting surface, mm

$$\Delta y := L \cdot \sin(\theta_w) \qquad \Delta y = 2.793 \times 10^{-1}$$

Gaussian intensity distributiion fcn, W/mm^2

$$I(x, y) := \frac{2 \cdot P_T}{\pi \cdot w^2} \cdot e^{-2 \cdot \frac{x^2 + y^2}{w^2}}$$

relative power retroreflected, W

$$\Delta P_{flat} := 2 \cdot \int_{163.2}^{163.2+\Delta y} \int_{0}^{x_{flat}} I(x, y)\, dx\, dy$$

$$\Delta P_{flat} = 8.104 \times 10^{-11}$$

fractional power retroflected from both flats, W

$$\eta_{flat} := \frac{2 \cdot R_{AR} \cdot R_{fb} \cdot \Delta P_{flat} \cdot T_{HR}^{2}}{P_{coc}}$$

$$\eta_{flat} = 2.026 \times 10^{-19}$$

relative field amplitude ratio

$$\eta_{ampflat} := \sqrt{\eta_{fla}}$$

$$\eta_{ampflat} = 4.501 \times 10^{-10}$$

2.2 Relative Scattered Light Noise from Flats

The COC is suspended from a quadruple pendulum. The displacement noise requirement at the suspended HR surface of the COC at 10 Hz is < 10E-19 m/rt Hz, see G070482-00. The displacement noise decreases as f^-8 for f> 10 Hz.

mirror motion, m/rt Hz

$$x_m(f) := 1 \cdot 10^{-19} \cdot \left(\frac{10}{f}\right)^{8}$$

mirror motion @ 100 Hz, m/rt Hz

$$x_m(100) = 1 \times 10^{-27}$$

SRD displacement @ 100 Hz, m/rt Hz

$$X_{srd} := 1 \cdot 10^{-20}$$

relative scattered light noise

$$f := \frac{\eta_{ampflat} \cdot x_m(100)}{X_{srd}}$$

$$f = 4.501 \times 10^{-17}$$

2.3 Retro-reflected Power from the Barrel

The corner formed by the barrel surface and the AR surface of the COC would also form a retro-reflector if the flats were not present. The extent of the retro-reflecting surface is smaller than that of the flats.

The results are shown below.

azimuthal extent of retro-reflecting surface, rad

$$\phi := 5 \cdot \frac{\pi}{180}$$

radial extent of retro-reflecting surface, mm

$$\Delta r := L \cdot \sin(\theta_w)$$

$$\Delta r = 2.793 \times 10^{-1}$$

Gaussian intensity distribution fcn, W/mm^2

$$I(r) := \frac{2 \cdot P_T}{\pi \cdot w^2} \cdot e^{-2 \cdot \frac{r^2}{w^2}}$$

power in the retro-reflecting segment, W

$$\Delta P_{barrel} := I(R) \cdot R \cdot \phi \cdot \Delta r$$

fractional power retro-flected from the barrel, W

$$\eta_{barrel} := \frac{R_{AR} \cdot R_{fb} \cdot \Delta P_{barrel} \cdot T_{HR}^{2}}{P_{coc}}$$

$$\eta_{barrel} = 5.484 \times 10^{-21}$$

relative field amplitude ratio

$$\eta_{ampbarrel} := \sqrt{\eta_{barrel}}$$

$$\eta_{ampbarrel} = 7.405 \times 10^{-11}$$

2.4 Relative Scattered Light Noise from Barrel

relative scattered light noise

$$f := \frac{\eta_{ampbarrel} \cdot x_m(100)}{x_{srd}}$$

$$f = 7.405 \times 10^{-18}$$

3 Conclusion

The retro-reflected electric field from the flats of the COC test mass mirrors is about 6 times greater than that retro-reflected from the barrel, if there had been no flats. This retro-reflected electric field will have a varying phase relationship to the electric field inside the arms and may cause a fringe contrast deficit and/or phase noise.

The retro-reflected field can be considered as a scattered light source from the surface of a suspended COC. The relative scattered light noise is estimated to be about sixteen orders of magnitude lower than the ADLIGO scattered light requirement and is negligible.