LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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ALS Arm Cavity Baffle Photodetector Array

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1 Introduction

A vacuum compatible ALS photodiode array is placed around the circumference of in the Arm Cavity Baffle hole. The photodiodes will be used for aligning the arm cavity mirrors and for pointing the Power Recycling Cavity beam.

When the IFO is in lock, each ALS photodiode will receive less than 1 microwatt from the wings of the 830000 W arm cavity beam.

The dominant light flux on the ALS photodiodes will come from the scattered light from the opposite COC at the far end of the arm--this scattered light will illuminate each photodiode with approximately 4 E-3 W. The ALS photodiodes will provide a diagnostic tool for monitoring the scattered light from the COC arm cavity mirrors.

1.1 Applicable Documents

T080064-00 Controlling Light Scatter in Advanced LIGO

T060073-00 Transfer Functions of Injected Noise

T0900269-v3 Stray Light Control (SLC) Preliminary Design

2 Description of the Apparatus

The photodetector assemblies in their housings are mounted to the back side of the baffle, as shown in Figure 1, using stainless steel flat head screws that are visible from the beam side, with an opening in the baffle that allows only the active photodetector surface to be in the line of sight of the light from the far arm.

The detail of the photodetector assembly is shown in Figure 2.

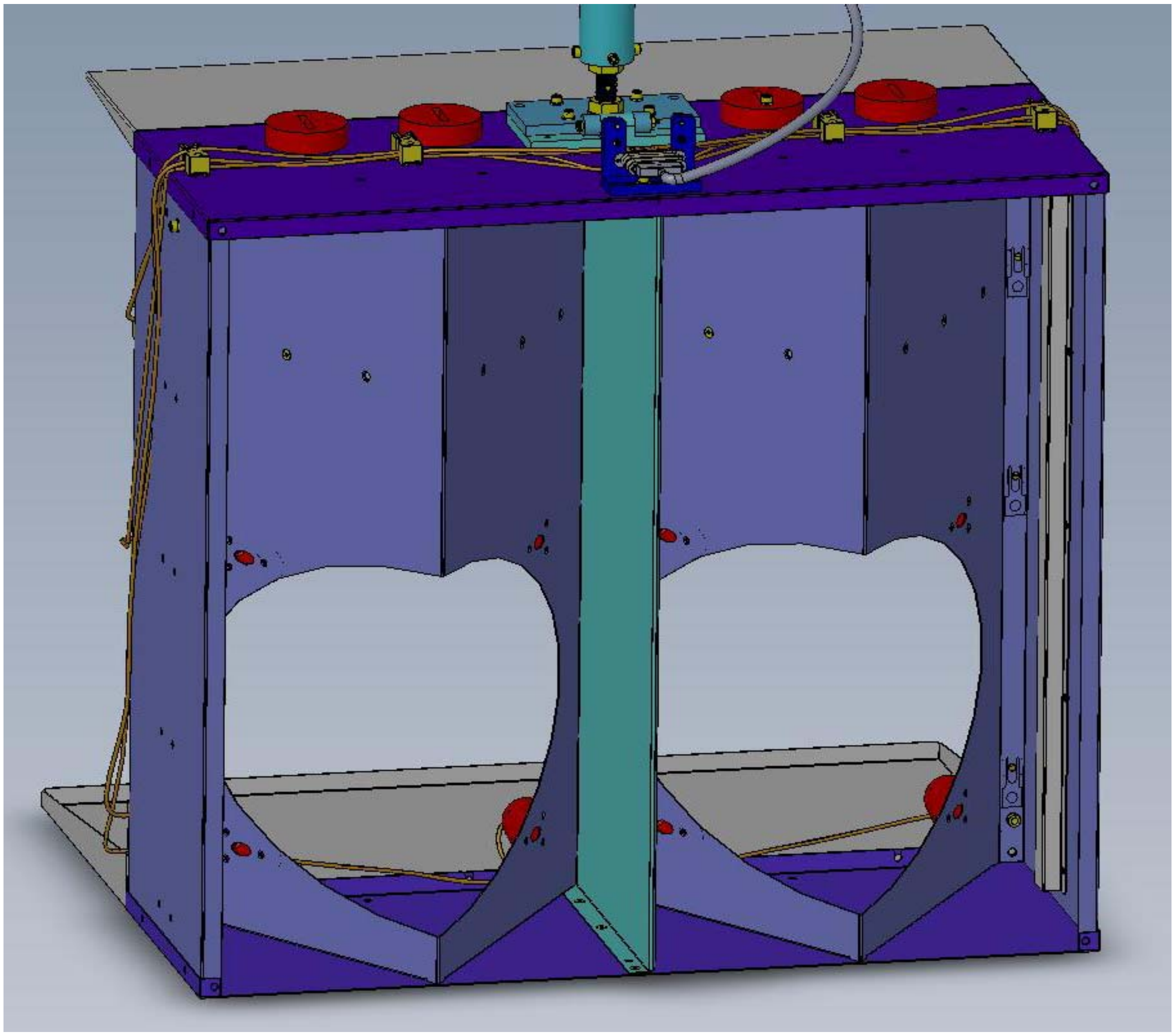

Figure 1: ALS Arm Cavity Baffle Assembly

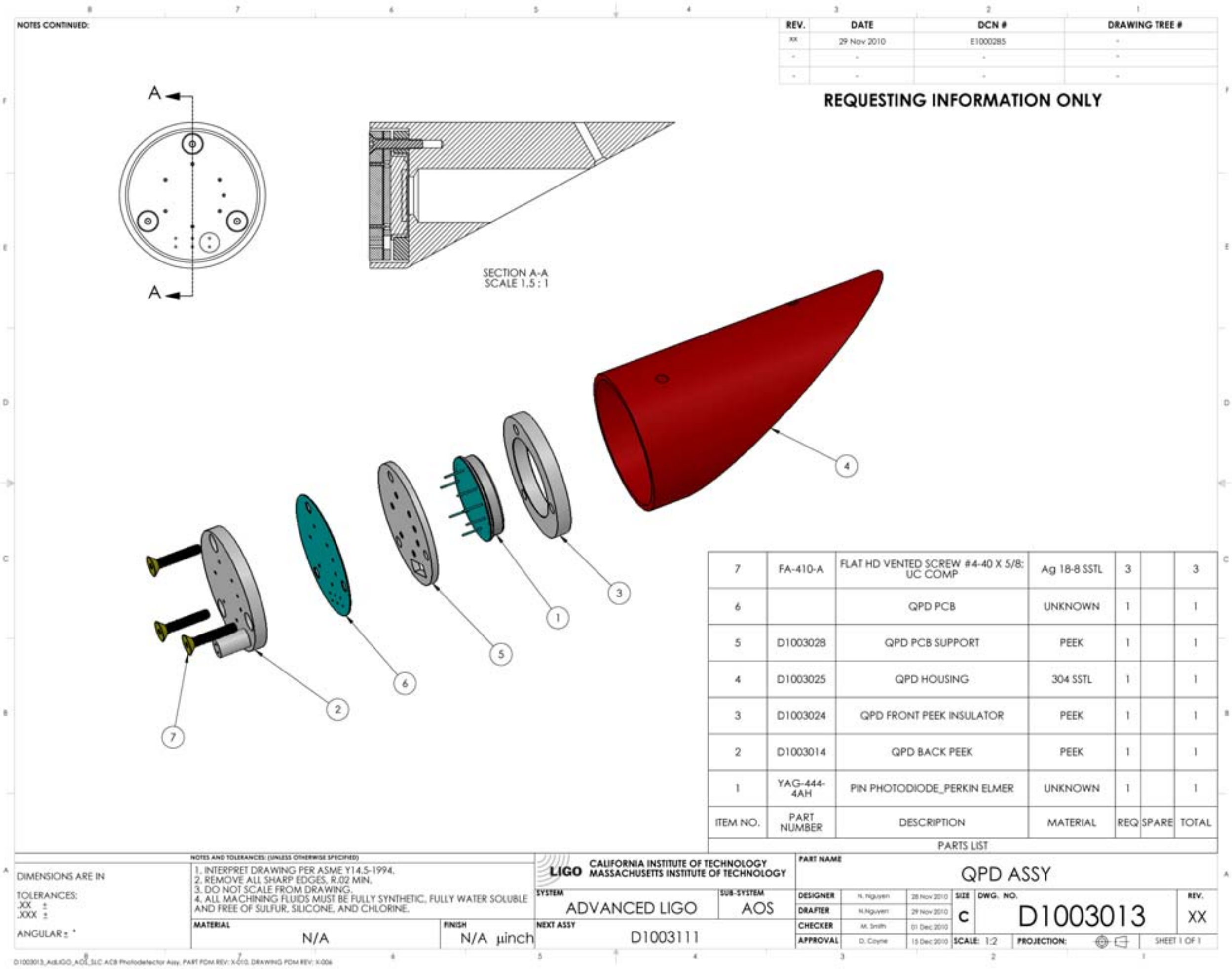

Figure 2: ALS Photodetector Assembly

3 Scattered Light Displacement Noise of ALS Photodetector Array

The photodetector surfaces and the heads of the mounting screws will scatter the main beam and the COC scattered light beam from the far end of the beam tube. The displacement noise caused by these scattering sources is two orders of magnitude less than that of the Arm Cavity Baffle surface

3.1 Scattered Light Calculation Parameters

laser wavelength, m	$\lambda := 1.064 \cdot 10^{-6}$
wave number, m^-1	$k := 2 \cdot \frac{\pi}{\lambda}$
	$k = 5.9052 \times 10^{6}$
IFO waist size, m	$w_{ifo} := 0.012$

solid angle of IFO mode, sr $\Delta_{ifo} := \dfrac{\lambda^2}{\pi \cdot w_{ifo}^{\,2}}$

$\Delta_{ifo} = 2.5025 \times 10^{-9}$

Transfer function @ 100 Hz, ITM HR $TF_{itmhr} := 1.1 \cdot 10^{-9}$

Gaussian beam radius at ITM, m $w := 0.055$

IFO arm length, m $L := 4000$

PSL laser power, W $P_{psl} := 125$

Arm Power, W $P_0 := 834174$

BRDF, sr^-1; CSIRO, surface 2, S/N 2 $BRDF_1(\theta) := \dfrac{2755.12}{\left(1 + 8.50787 \cdot 10^8 \cdot \theta^2\right)^{1.23597}}$

BRDF_porcelain_ss $BRDF_{porc} := 2 \cdot 10^{-3}$

BRDF of photodetector, sr^-1 $BRDF_{pd} := 1 \cdot 10^{-3}$

BRDF of screw head sr^-1 $BRDF_{sh} := 5 \cdot 10^{-2}$

BRDF_COC_30urad, sr^-1 $BRDF_{COC} := BRDF_1\left(30 \cdot 10^{-6}\right)$

$BRDF_{COC} = 1.3644 \times 10^3$

number of photodetector $N_{pd} := 16$

number of screw heads $N_{sh} := 48$

radius of photodetector ring, m $r_{pdbc} := 0.196$

Photoconductor radius, m $r_{pd} := \dfrac{0.0114}{2}$

$r_{pd} = 5.7 \times 10^{-3}$

photoconductor area, m^2 $A_{pd} := \pi \cdot r_{pd}^{2}$

$A_{pd} = 1.0207 \times 10^{-4}$

Screw head radius, m $r_{sh} := .0038$

Screw head area, m^2 $A_{sh} := \pi \cdot r_{sh}^{2}$

$A_{sh} = 4.5365 \times 10^{-5}$

3.2 Scattering from Main Beam

3.2.1 Power Hitting Photodetector Surface and Screw Head

irradiance function at ACB, W/m^2 $I_{pd}(r) := 2 \cdot \frac{P_0}{\pi \cdot w^2} \cdot e^{-2 \cdot \left(\frac{r^2}{w^2}\right)}$

total beam power, W $P_0 := \int_0^{10w} 2 \cdot \pi \cdot r \cdot I_{pd}(r)\, dr$

$P_0 = 8.3417 \times 10^{5}$

Irradiance at photodetector, W/m^2 $I_{pd}\left(r_{pdbc}\right) = 1.6359 \times 10^{-3}$

Power hitting each PD, W $P_{pd} := I_{pd}\left(r_{pdbc}\right) \cdot A_{pd}$

$P_{pd} = 1.6698 \times 10^{-7}$

Power hitting each screw head, W $P_{sh} := I_{pd}\left(r_{pdbc}\right) \cdot A_{sh}$

$P_{sh} = 7.4213 \times 10^{-8}$

3.2.2 Power Scattered into IFO Mode

half-angle from centerline to inner edge of PD, rad

$$\theta_{pdi} := \frac{\left(r_{pdbc} - r_{pd}\right)}{L}$$

half-angle from centerline to outer edge of PD, rad

$$\theta_{pdo} := \frac{\left(r_{pdbc} + r_{pd}\right)}{L}$$

average angle, rad

$$\theta_{pd} := \frac{\theta_{pdi} + \theta_{pdo}}{2}$$

$$\theta_{pd} = 4.9 \times 10^{-5}$$

BRDF at photodetector, angle, sr^-1

$$BRDF_1\left(4.9 \times 10^{-5}\right) = 696.3695$$

3.2.2.1 Scattering by Photodetector

power scattered by photodetector, into IFO mode, W

$$P_{pds} := \sqrt{N_{pd}} \cdot P_{pd} \cdot BRDF_{pd} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^{2}} \cdot BRDF_1\left(4.9 \times 10^{-5}\right) \cdot \Delta_{ifo}$$

$$P_{pds} = 3.291 \times 10^{-26}$$

3.2.2.2 Scattering by Screw Head

power scattered by screw head into IFO mode, W

$$P_{shs} := \sqrt{N_{sh}} \cdot P_{sh} \cdot BRDF_{sh} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^{2}} \cdot BRDF_1\left(4.9 \times 10^{-5}\right) \cdot \Delta_{ifo}$$

$$P_{shs} = 1.2667 \times 10^{-24}$$

3.2.3 Displacement Noise

ACB displacement @ 100 HZ, m/rt HZ $x_{ACB} := 1 \cdot 10^{-12}$

displacement noise @ 100 Hz, m/rtHz

$$DN_{acbpd} := TF_{itmhr} \cdot \left(\frac{P_{pds}}{P_{psl}}\right)^{0.5} \cdot x_{ACB} \cdot 2 \cdot k$$

$$DN_{acbpd} = 2.108 \times 10^{-28}$$

3.3 Scattering from COC Scattered Light

3.3.1 Power Hitting Photodetector Surface and Screw Head

COC Scattered power hitting the PD, W $P_{cocpd} := P_0 \cdot BRDF_1(\theta_{pd}) \cdot \frac{A_{pd}}{L^2} = 3.7057 \times 10^{-3}$

COC Scattered power hitting the screw head W $P_{cocsh} := P_0 \cdot BRDF_1(\theta_{pd}) \cdot \frac{A_{sh}}{L^2} = 1.647 \times 10^{-3}$

3.3.2 Power Scattered into IFO Mode

3.3.2.1 Scattering by Photodetector

power scattered by photodetector, into IFO mode, W

$$P_{cocpds} := \sqrt{N_{pd}} \cdot P_{cocpd} \cdot BRDF_{pd} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^2} \cdot BRDF_1\left(4.9 \times 10^{-5}\right) \cdot \Delta_{ifo}$$

$$P_{cocpds} = 7.3036 \times 10^{-22}$$

3.3.2.2 Scattering by Screw Head

power scattered by screw head
into IFO mode, W

$$P_{cocshs} := \sqrt{N_{sh}} \cdot P_{cocsh} \cdot BRDF_{sh} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^{2}} \cdot BRDF_{1}\left(4.9 \times 10^{-5}\right) \cdot \Delta_{ifo}$$

$$P_{cocshs} = 2.8112 \times 10^{-20}$$

3.3.3 Displacement Noise

displacement noise @ 100 Hz, m/rtHz

$$DN_{cocpd} := TF_{itmhr} \cdot \left(\frac{P_{cocpds}}{P_{psl}}\right)^{0.5} \cdot x_{ACB} \cdot 2 \cdot k$$

$$DN_{cocpd} = 3.1403 \times 10^{-26}$$

$$DN_{cocsh} := TF_{itmhr} \cdot \left(\frac{P_{cocshs}}{P_{psl}}\right)^{0.5} \cdot x_{ACB} \cdot 2 \cdot k$$

$$DN_{cocsh} = 1.9483 \times 10^{-25}$$

The full scattering displacement noise spectrum is shown in Figure 3, and is compared with the AOS requirement.

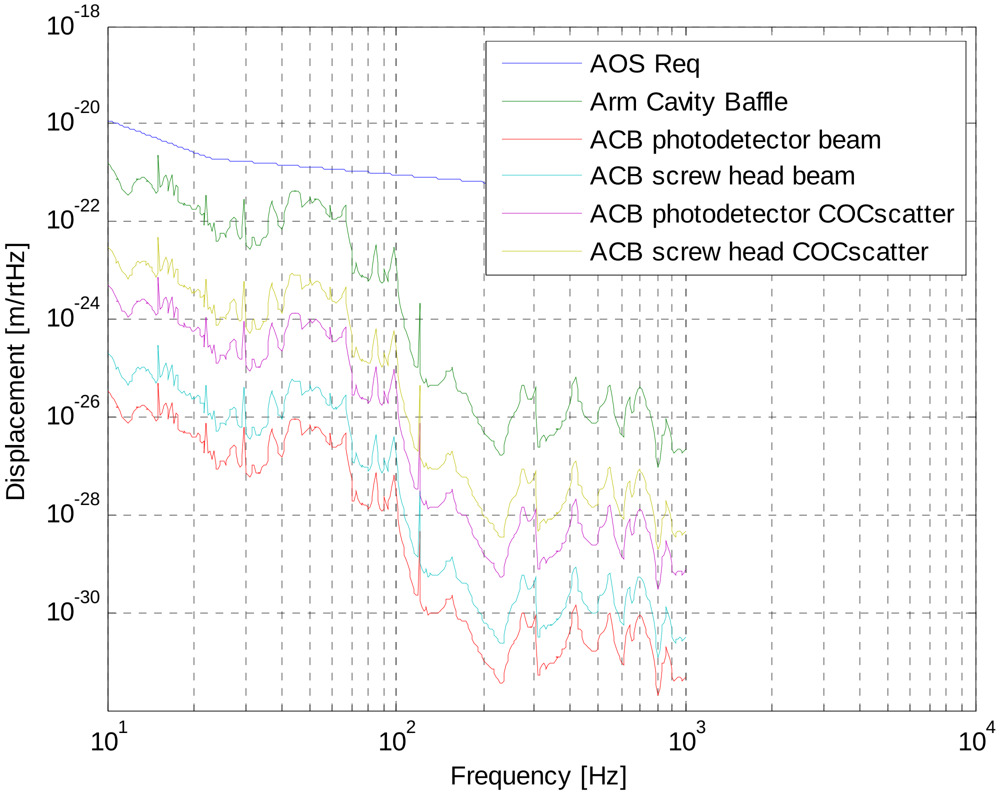

Figure 3: Scattered Light Displacement Noise from Arm Cavity Beam, and from the COC Scattered Light

4 ALS Alignment Signals for Initial Lock

The aLIGO IFO Arm Cavity alignment for initial lock will be accomplished using the ALS Green beam, launched from behind the ETM, and the PSL beam.

ALS photodetectors placed around the perimeter of the hole in the Arm Cavity Baffle will provide signals that enable the pointing of the ALS Green beam, and the PR3 mirror.

The alignment procedure will consist of

1. scanning the pointing direction of the ALS Green beam toward the ITM until a signal is received on the ALS photodetectors in the ITM Arm Cavity Baffle. Thereafter, the ALS beam will be steered to the center of the ITM by equalizing the received signals on the four photodetectors that effectively form an extended QPD centered on the COC.
2. Similarly, the ITM will be steered to reflect the ALS beam back toward the ETM, and the beam will be centered on the ETM by using the ALS photodetectors in the ETM Arm Cavity Baffle, with a final centering achieved by the Transmon signal itself, transmitting through the ETM and the Transmon telescope.

3. The PR3 mirror will steer the PSL beam so that the 1064nm beam hits the ALS photodetectors in the ETM Arm Cavity Baffle, and is centered on the ETM by equalizing the photodetector signals.
4. The ETM will be steered by either observing the transmitted Transmon signal, or by reflecting the PSL beam back toward the ITM Arm Cavity ALS photodetectors.

4.1 Parameters

532 laser wavelength, m	$\lambda_{532} := 0.532 \cdot 10^{-6}$
1064 laser wavelength, m	$\lambda_{1064} := 1.064 \cdot 10^{-6}$
IFO waist size, m	$w_{ifo} := 0.012$
Gaussian beam radius 1064 beam at ITM, m	$w_{1064} := 0.05$
Gaussian beam radius 532 beam at ITM, m	$w_{532} := 0.055 \sqrt{\frac{\lambda_{532}}{\lambda_{1064}}}$
PSL laser power, W	$P_{psl} := 125$
transmissivity of PRM	$T_{prm} := 0.03$
transmissivity of ITM	$T_{itm} := 0.014$
radius of photodetector ring, m	$r_{pdbc} := 0.196$
Photoconductor radius, m	$r_{pd} := \frac{0.0114}{2}$
photoconductor area, m^2	$A_{pd} := \pi \cdot r_{pd}^{2}$

4.2 ALS Green Beam Signal

532 laser power, W

$$P_{532} := 0.1$$

532 irradiance function at ACB, W/m^2

$$I_{532pd}(r) := 2 \cdot \frac{P_{532}}{\pi \cdot w_{532}^{2}} \cdot e^{-2 \cdot \left(\frac{r^{2}}{w_{532}^{2}}\right)}$$

Irradiance at photodetector, W/m^2

$$I_{532pd}(0) = 42.091$$

Power hitting each PD, W

$$P_{532pd} := I_{532pd}(0) \cdot A_{pd}$$

$$P_{532pd} = 4.296 \times 10^{-3}$$

4.3 PSL 1064 nm Signal

1064 laser power, W

$$P_{1064} := P_{psl} \cdot T_{prm} \cdot T_{itm}$$

$$P_{1064} = 0.053$$

1064 irradiance function at ACB, W/m^2

$$I_{1064pd}(r) := 2 \cdot \frac{P_{1064}}{\pi \cdot w_{1064}^{2}} \cdot e^{-2 \cdot \left(\frac{r^{2}}{w_{1064}^{2}}\right)}$$

Irradiance at photodetector, W/m^2

$$I_{1064pd}(0) = 11.049$$

Power hitting each PD, W

$$P_{1064pd} := I_{1064pd}(0) \cdot A_{pd}$$

$$P_{1064pd} = 1.128 \times 10^{-3}$$