LIGO-T1200175-v1 4/10/12

LCGT

bLCGT TM Wide Angle Baffle, Manifold Baffle, and Beam Tube Baffle Conceptual Design

Michael Smith

Table of Contents

Table of Figures

1 INTRODUCTION

This document presents a conceptual design for the bLCGT Test Mass (TM) Wide Angle Baffle, Manifold Baffle, and Beam Tube Baffles.

The function of the Wide Angle Baffle is to mitigate the backscattered displacement noise of the wide angle scattered light from the ITM and ETM test mass HR surfaces.

The function of the Manifold Baffle is to shield the cryo baffles from scattered light coming from the far TM mirror at the opposite end of the beam tube.

The function of the Beam Tube Baffles is to reduce the displacement noise that would result from the small angle scattered light from the TM mirror hitting the wall of the beam tube.

1.1 Applicable Documents

2 WIDE ANGLE BAFFLE

2.1 TM WIDE ANGLE BAFFLE (WAB) DESCRIPTION

The TM Wide Angle Baffle is placed near the ITM and ETM HR surfaces. It functions to catch the wide angle scattered light from the point defects in the TM HR coating.

2.1.1 General Baffle Assembly

The baffle is made of oxidized polished stainless steel, with the polished surface facing toward the opposite end of the arm. The hole diameter in the baffle is slightly larger than the diameter of the ITM and ETM mirrors.

The scattering could be reduced significantly by coating the surfaces of the baffle with DLC coating.

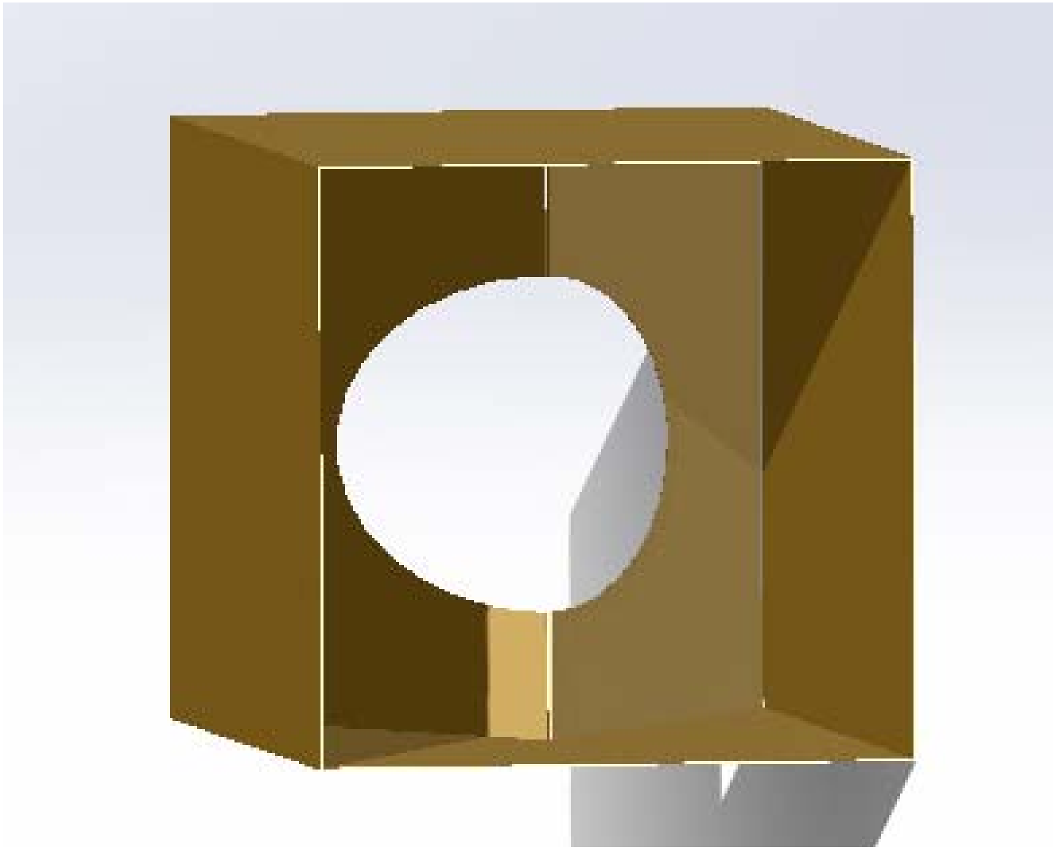


Figure 1: Wide Angle Baffle

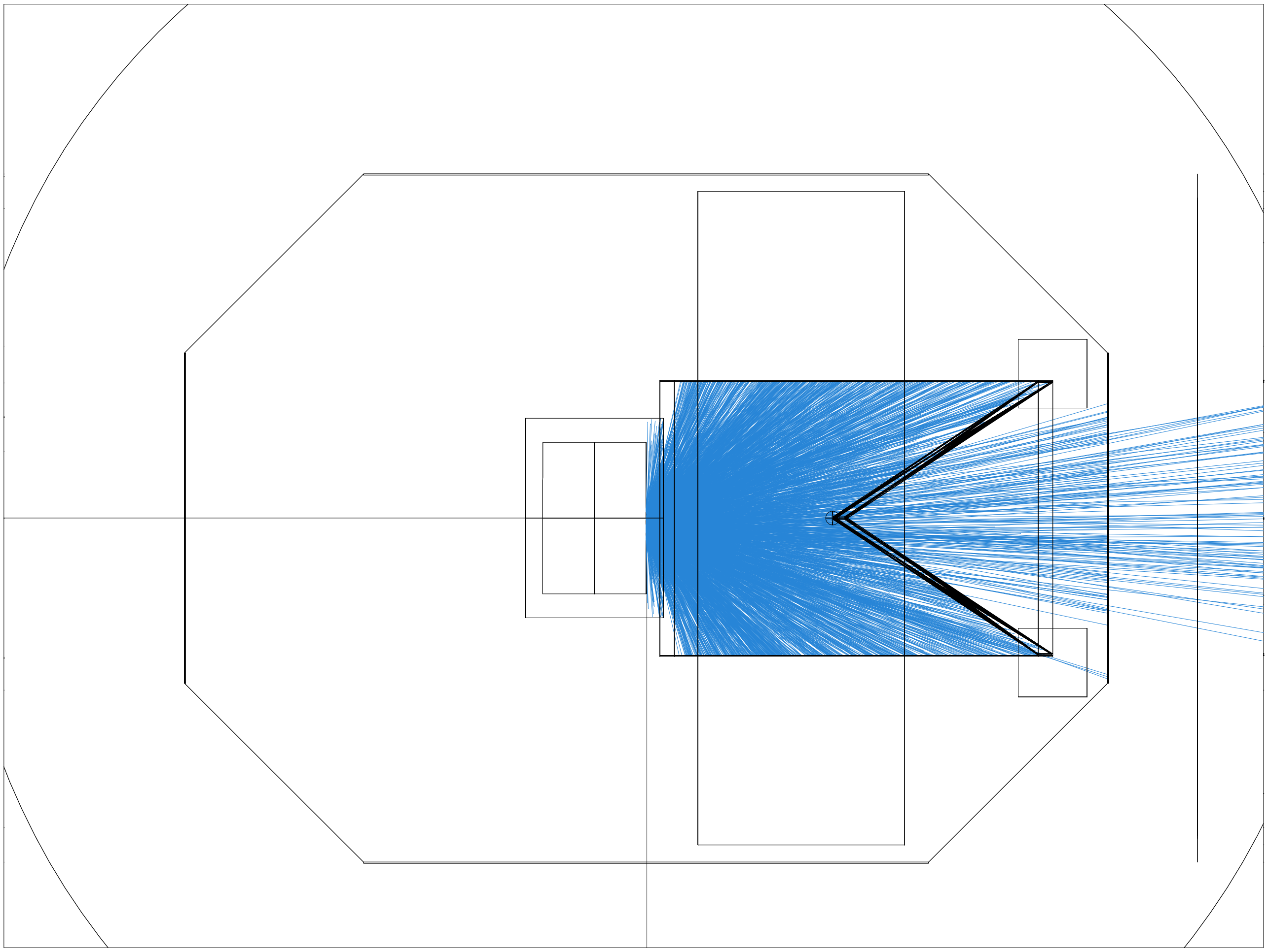


Figure 2: Top view of Wide Angle Baffle, shown catching wide angle scattered light from HR surface of ITM

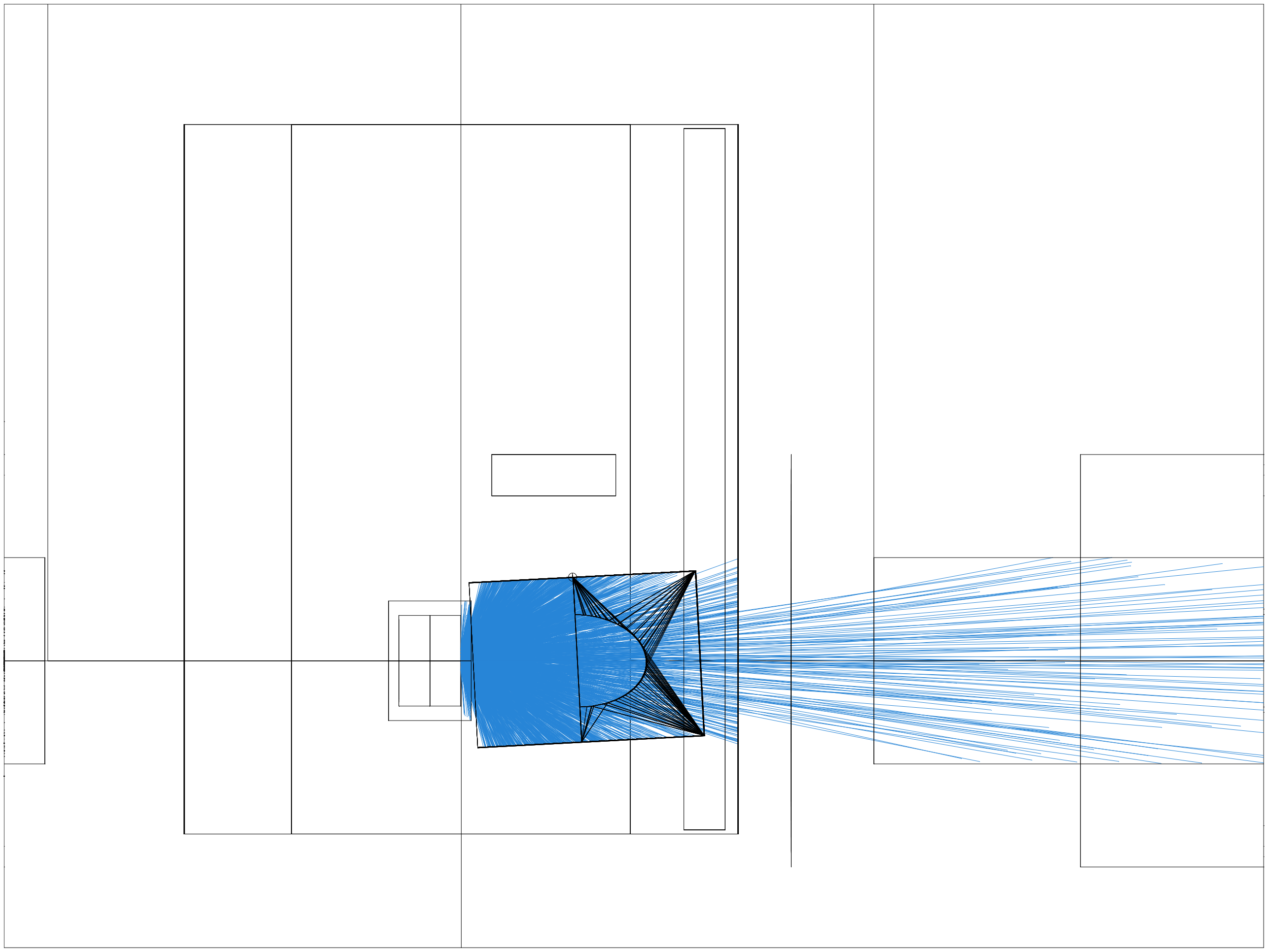


Figure 3: Side view of Wide Angle Baffle, shown catching wide angle scattered light from HR surface of ITM

Figure 4: Fractional Wide Angle Scattered Power Hitting Surfaces

Surface	Power fraction
Wide Angle Baffle	0.918
Thermal Baffles In Manifold	0.039
Front Side Cryo-Shield	0.039
Reaction Mass	0.005
Total Power	1.000

The power hitting the Wide Angle Baffle with 10ppm scattering of a 400kW beam from the surface of the test mass will be approximately 4 W; with a 100ppm scattering, the power will be approximately 40 W.

2.1.2 TM WIDE ANGLE BAFFLE LOCATIONS

The baffle is placed in close proximity to the ITM and ETM test mass (TM) HR surface.

2.1.3 Mechanical Interfaces

The WAB is attached directly to the cryoshield or may be suspended from a suitable suspension. The baffle will be tipped approximately 3 deg in the direction of the beam tube to reduce the direct reflection from the edges of the baffle hole back toward the far TM.

2.1.4 Optical Interfaces

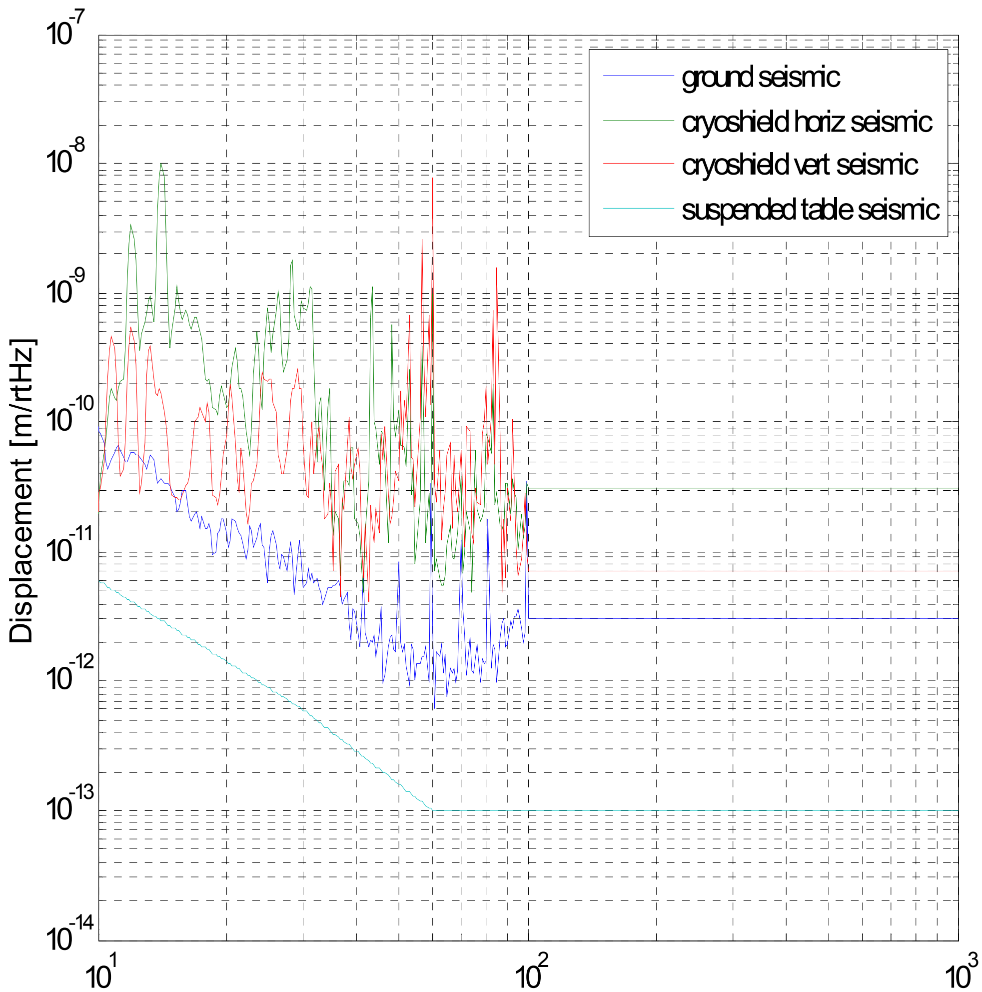
2.1.4.1 Main IFO Beams

The radius of the Wide Angle Baffle is 122 mm, which allows a 2 mm positioning tolerance with respect to the centerline of the TM.

2.1.5 TM WIDE ANGLE BAFFLE SCATTER

2.1.5.1 Seismic Motion of the Wide Angle Scattering Surfaces.

The Wide Angle Baffle is assumed to be attached directly to the cryoshield with the motion spectrum shown in the figure below.



Seismic Motion, m/rtHz

2.1.5.2 Wide Angle Baffle Suspension Transmissibility

For the scattered light calculations, it was assumed that the Wide Angle Baffle was connected directly to the Cryogenic shield enclosure. However, it is probably advisable to suspend it to reduce the scattered light displacement noise.

2.1.5.3 Beam Dump Surface BRDF

It is proposed to construct the baffles from polished oxidized steel with the first surface inclined at an incidence angle 57 deg. The measured BRDF is < 0.03 sr^{-1}.

However, a recent measurement of the BRDF of DLC coating, as shown in Figure 5, indicates that it has a scattering BRDF approximately 4 orders of magnitude less than oxidized stainless steel; with the DLC coating, it may be possible to eliminate the need for suspending the baffle. The DLC coating is applied directly to the polished stainless steel surface, and may also be applied to an aluminum surface to provide better thermal conductivity within the baffle structure to enable cryogenic cooling.

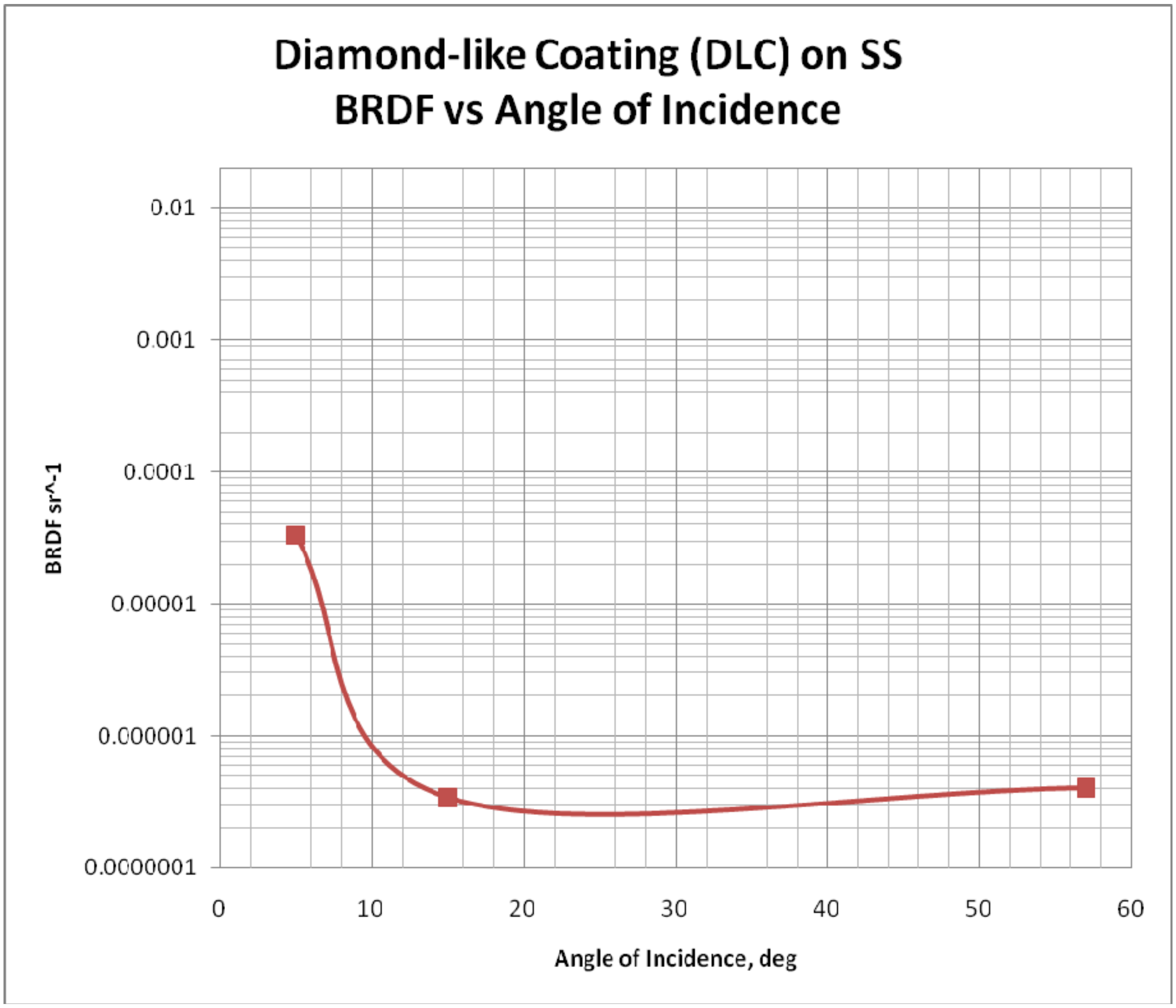


Figure 5: BRDF of DLC Coating on Polished Stainless Steel

2.1.5.4 DARM Motion Transfer Functions

The DARM motion transfer functions used for calculating the scattered light displacement noise are shown below (Ref. Yioichi Aso).

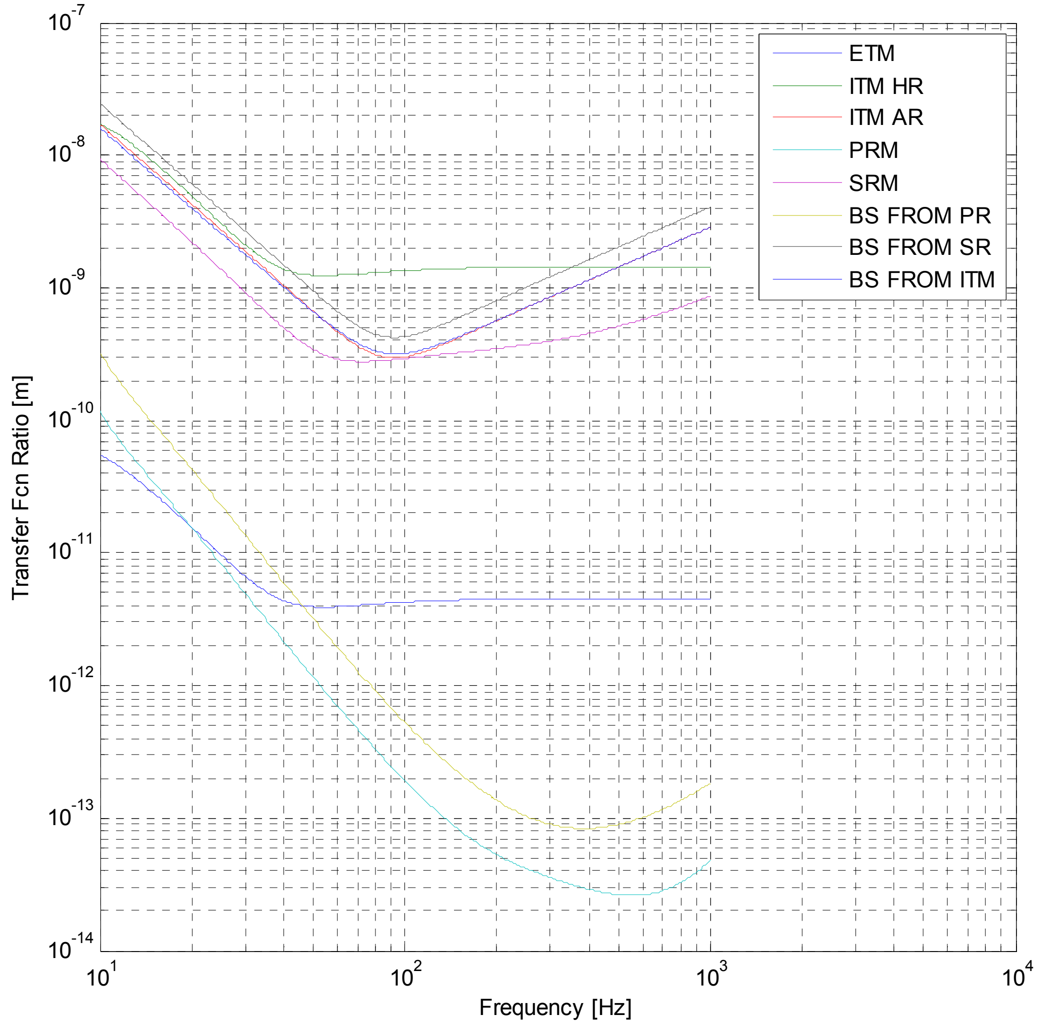


Figure 6: DARM motion transfer functions

2.1.5.5 Wide Angle Baffle Scatter Calculations

IFO arm length, m	$L_{arm} := 3000$
Minimum displacement detectivity @ 100 Hz, m/rt Hz	$D_{min100} := 3.95894e\text{-}24 L_{arm}$
	$D_{min100} = 1.188 \times 10^{-20}$
seismic displacement @ 100 HZ, m/rt HZ	$x_g := 9 \cdot 10^{-11}$
cryo shield displacement @ 100 HZ, m/rt HZ	$x_{cryo} := 9 \cdot 10^{-11}$
Wide angle baffle motion attenuation @ 100 HZ, m/rt HZ	$A_{wab} := 1$
Wide Angle Baffle displacement @ 100 Hz, m/rtHz	$x_{wab} := x_g \cdot A_{wab}$
Transfer function @ 100 Hz, ITM HR	$TF_{itmhr} := 1.1 \cdot 10^{-9}$
BRDF of chamber wall, sr^-1	$BRDF_{wall} := 0.1$
BRDF of oxidized polished steel, sr^-1	$BRDF_{oxipolish} := 0.03$
BRDF of stainless steel, sr^-1	$BRDF_{oxiunpolish} := 0.1$
BRDF of thermal baffle, sr^-1	$BRDF_{thermal} := 0.03$
BRDF of cryo shield sr^-1	$BRDF_{cryo} := 0.03$
laser wavelength, m	$\lambda := 1.064 \cdot 10^{-6}$

wave number, m^-1 $k := 2 \cdot \frac{\pi}{\lambda}$

solid angle of IFO mode, sr $\Delta\Omega_{ifo} := \frac{\lambda^2}{\pi \cdot w_{ifo}^2} = 1.668 \times 10^{-9}$

hemispherical scattering loss fraction
TM wide angle(ref: T070089) $\alpha_{TM} := 10 \times 10^{-6}$

arm power, W $P_a := 4 \times 10^5$

input laser power, W $P_{psl} := 50$

FOR THE FOLLOWING DATA, SEE:
/LCGT/Wide Ange Baffle_Manifold Baffle_Beam Tube Baffle/WIDE ANGLE BAFFLE SCATTERED POWER.xlsx

PATH LENGTH FROM SCATTER SOURCE

distance from ITM to scattering surface, m

ARM-CAVITY-BAF-PLATE-2, m $L_{wab1} := 0.457$

ARM-CAVITY-BAF-PLATE-3, m $L_{wab2} := 0.457$

ACB_WIDE-ANGLE-BAFFLE-SIDE L, m $L_{wab3} := 0.355$

ACB_WIDE-ANGLE-BAFFLE-SIDE R, m $L_{wab4} := 0.355$

WIDE-ANGLE-BAF-TOP-LEDGE, m $L_{wab5} := 0.355$

WIDE-ANGLE-BAF-BOTTOM-LEDGE, m $L_{wab6} := 0.349$

FRONT-SIDE-CRYO, m $L_{cryo} := 0.703$

thermal-baffle, m $L_{thermal} := 1.756$

TM INCIDENT ANGLE FROM SCATTER SOURCE

ARM-CAVITY-BAF-PLATE-2, rad $\theta_{wab1} := 0.41$

ARM-CAVITY-BAF-PLATE-3, rad $\theta_{wab2} := 0.41$

ACB_WIDE-ANGLE-BAFFLE-SIDE L, rad $\theta_{wab3} := 0.6$

ACB_WIDE-ANGLE-BAFFLE-SIDE R, rad $\theta_{wab4} := 0.6$

WIDE-ANGLE-BAF-TOP-LEDGE5, rad $\theta_{wab5} := 0.6$

WIDE-ANGLE-BAF-BOTTOM-LEDGE, rad $\theta_{wab6} := 0.58$

FRONT-SIDE-CRYO, rad $\theta_{cryo} := 0.33$

thermal-baffle rad $\theta_{thermal} := 0.2$

FRACTIONAL POWER ONTO SCATTER SOURCE

ARM-CAVITY-BAF-PLATE-2 $PF_{wab1} := 0.08$

ARM-CAVITY-BAF-PLATE-3 $PF_{wab2} := 0.08$

ACB_WIDE-ANGLE-BAFFLE-SIDE L $PF_{wab3} := 0.20$

ACB_WIDE-ANGLE-BAFFLE-SIDE R $PF_{wab4} := 0.20$

WIDE-ANGLE-BAF-TOP-LEDGE $PF_{wab5} := 0.17$

FRONT-SIDE-CRYO $PF_{cryo} := 0.039$

THERMAL-BAFFLES $PF_{thermal} := 0.039$

POWER FROM TM INCIDENT ONTO SCATTERING SURFACE

Power incident on baffle surface $P_s := P_a \cdot \alpha_{TM} \cdot PF_s$

ARM-CAVITY-BAF-PLATE-2, W $P_{wab1} := P_a \cdot \alpha_{TM} \cdot PF_{wab1}$

ARM-CAVITY-BAF-PLATE-3, rad $P_{wab2} := P_a \cdot \alpha_{TM} \cdot PF_{wab2}$

ACB_WIDE-ANGLE-BAFFLE-SIDE L, W $P_{wab3} := P_a \cdot \alpha_{TM} \cdot PF_{wab3}$

ACB_WIDE-ANGLE-BAFFLE-SIDE R, W $P_{wab4} := P_a \cdot \alpha_{TM} \cdot PF_{wab4}$

WIDE-ANGLE-BAF-TOP-LEDGE5, W $P_{wab5} := P_a \cdot \alpha_{TM} \cdot PF_{wab5}$

WIDE-ANGLE-BAF-BOTTOM-LEDGE, W $P_{wab6} := P_a \cdot \alpha_{TM} \cdot PF_{wab6}$

Total wide angle baffle incident power, W

$$P_{wabT} := P_{wab1} + P_{wab2} + P_{wab3} + P_{wab4} + P_{wab5} + P_{wab6}$$

$$P_{wabT} = 3.64$$

FRONT-SIDE-CRYO, W $P_{cryo} := P_a \cdot \alpha_{TM} \cdot PF_{cryo}$

$P_{cryo} = 0.156$

thermal-baffle. W $P_{thermal} := P_a \cdot \alpha_{TM} \cdot PF_{thermal}$

$P_{thermal} = 0.156$

Wide Angle Scatter Ref:
1) LIGO T070089 Wide Angle Scatter from LIGO Arm Cavities, P. Fritschel , M. E. Zucker
2) LIGO T1100113 Michael Smith

Power scattered from surface back into IFO mode

$$P_{sTMifo} := P_a \cdot \alpha_{TM}^{2} \cdot PF_s \cdot BRDF_s \cdot \frac{\lambda^2}{\pi \cdot L_s^{2}} \cdot \cos\left(\theta_{inc}\right)$$

ARM-CAVITY-BAF-PLATE-2, W

$$P_{sTMwab1ifo} := P_a \cdot \alpha_{TM}^{2} \cdot PF_{wab1} \cdot BRDF_{oxiss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab1}^{2}} \cdot \cos\left(\theta_{wab1}\right)$$

$$P_{sTMwab1ifo} = 5.064 \times 10^{-19}$$

ARM-CAVITY-BAF-PLATE-3, W

$$P_{sTMwab2ifo} := P_a \cdot \alpha_{TM}^{2} \cdot PF_{wab2} \cdot BRDF_{oxiss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab2}^{2}} \cdot \cos\left(\theta_{wab2}\right)$$

$$P_{sTMwab2ifo} = 5.064 \times 10^{-19}$$

ACB_WIDE-ANGLE-BAFFLE-SIDE L, W

$$P_{sTMwab3ifo} := P_a \cdot \alpha_{TM}^{2} \cdot PF_{wab3} \cdot BRDF_{oxipolishss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab3}^{2}} \cdot \cos\left(\theta_{wab3}\right)$$

$$P_{sTMwab3ifo} = 5.664 \times 10^{-19}$$

ACB_WIDE-ANGLE-BAFFLE-SIDE R, W

$$P_{sTMwab4ifo} := P_a \cdot \alpha_{TM}^{2} \cdot PF_{wab4} \cdot BRDF_{oxipolishss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab4}^{2}} \cdot \cos\left(\theta_{wab4}\right)$$

$$P_{sTMwab4ifo} = 5.664 \times 10^{-19}$$

WIDE-ANGLE-BAF-TOP-LEDGE5, W

$$P_{sTMwab5ifo} := P_a \cdot \alpha_{TM}^2 \cdot PF_{wab5} \cdot BRDF_{oxipolishss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab5}^2} \cdot \cos\left(\theta_{wab5}\right)$$

$$P_{sTMwab5ifo} = 4.814\times 10^{-19}$$

WIDE-ANGLE-BAF-BOTTOM-LEDGE, W

$$P_{sTMwab6ifo} := P_a \cdot \alpha_{TM}^2 \cdot PF_{wab6} \cdot BRDF_{oxipolishss} \cdot \frac{\lambda^2}{\pi \cdot L_{wab6}^2} \cdot \cos\left(\theta_{wab6}\right)$$

$$P_{sTMwab6ifo} = 5.345\times 10^{-19}$$

TOTAL WIDE ANGLE BAFFLE SCATTER INTO IFO

$$P_{sTMwabifo} := P_{sTMwab1ifo} + P_{sTMwab2ifo} + P_{sTMwab3ifo} + P_{sTMwab4ifo} + P_{sTMwab5ifo} + P_{sTMwab6ifo}$$

$$P_{sTMwabifo} = 3.162\times 10^{-18}$$

FRONT-SIDE-CRYO, W

$$P_{sTMcryoifo} := P_a \cdot \alpha_{TM}^2 \cdot PF_{cryo} \cdot BRDF_{cryo} \cdot \frac{\lambda^2}{\pi \cdot L_{cryo}^2} \cdot \cos\left(\theta_{cryo}\right)$$

$$P_{sTMcryoifo} = 3.228\times 10^{-20}$$

thermal-baffle, W

$$P_{sTMthermalifo} := P_a \cdot \alpha_{TM}^2 \cdot PF_{thermal} \cdot BRDF_{thermal} \cdot \frac{\lambda^2}{\pi \cdot L_{thermal}^2} \cdot \cos\left(\theta_{thermal}\right)$$

$$P_{sTMthermalifo} = 5.36\times 10^{-21}$$

DISPLACEMENT NOISE @ 100 Hz, m/rtHz

Wide Angle Baffle displacement noise

$$DN_{wabaf} := TF_{itmhr} \cdot \left(\frac{P_{sTMwabifo}}{P_{psl}} \right)^{0.5} \cdot x_g \cdot A_{wab} \cdot 2 \cdot k$$

$$DN_{wabaf} = 2.94 \times 10^{-22}$$

Front-side cryo-shield displacement noise

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

$$DN_{cryo} = 3.301 \times 10^{-23}$$

Thermal baffle displacement noise

$$DN_{thermal} := TF_{itmhr} \cdot \left(\frac{P_{sTMthermalifo}}{P_{psl}} \right)^{0.5} \cdot x_g \cdot 2 \cdot k$$

$$DN_{thermal} = 1.211 \times 10^{-23}$$

Minimum displacement detectivity
@ 100 Hz, m/rt Hz

$$D_{min100} = 1.188 \times 10^{-20}$$

2.1.5.6 Scatter from ACB Front by Far End TM Scatter

The scattered light from the far TM that passes through the Manifold Baffle aperture and hits the front of the Wide Angle Baffle will scatter light back into the IFO mode.

half-angle from centerline to Rmb, rad

$$\theta_{mb} := \frac{R_{mb}}{L_{arm}}$$

$$\theta_{mb} = 3.8\times 10^{-5}$$

half-angle from centerline to R_{wab}, rad

$$\theta_{wab} := \frac{R_{wab}}{L_{arm}}$$

$$\theta_{wab} = 3.733\times 10^{-5}$$

BRDF, sr^-1; CSIRO, surface 2, S/N 2

$$BRDF_1(\theta) := \frac{2755.12}{\left(1 + 8.50787\cdot 10^{8}\cdot\theta^2\right)^{1.23597}}$$

power incident on WAB front, W

$$P_{wabfront} := P_a\cdot\int_{\theta_{wab}}^{\theta_{mb}} 2\cdot\pi\cdot\theta\cdot BRDF_1(\theta)\, d\theta$$

$$P_{wabfront} = 0.065$$

Power Scattered into IFO

$$P_{wabsifo} := \sqrt{N_{acb}}\cdot P_{wabfront}\cdot BRDF_{oxipolishss}\cdot\frac{\pi\cdot w_{ifo}^2}{L_{arm}^2}\cdot BRDF_1\left(\theta_{mb}\right)\cdot\Delta\Omega_{ifo}$$

$$P_{wabsifo} = 5.048\times 10^{-19}$$

Front-side WAB displacement noise @ 100 Hz, m/rtHz

$$DN_{wabfront} := TF_{itmhr}\cdot\left(\frac{P_{wabsifo}}{P_{psl}}\right)^{0.5}\cdot x_{cryo}\cdot 2\cdot k$$

$$DN_{wabfront} = 1.305\times 10^{-22}$$

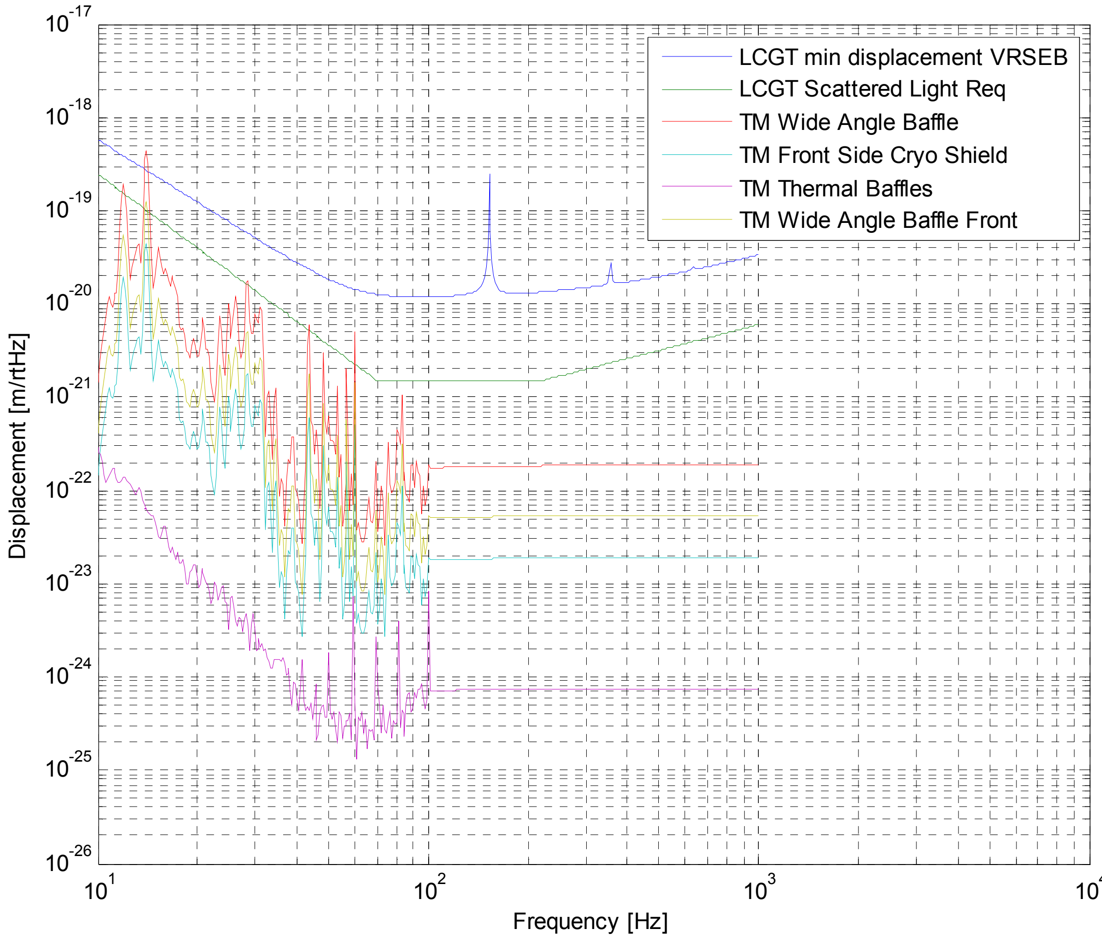
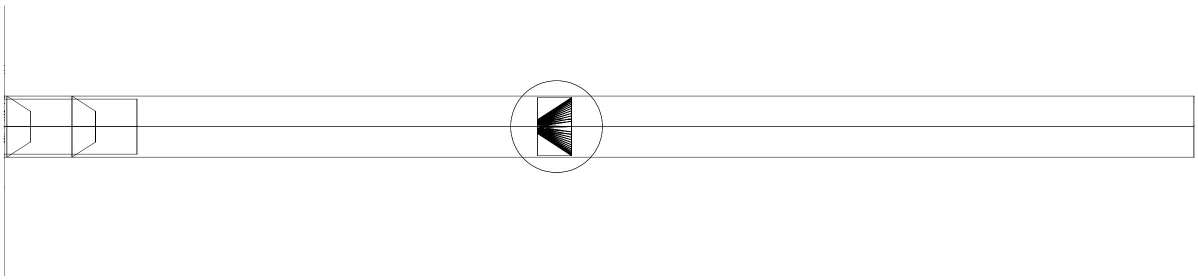


Figure 7: Displacement Noise from TM Wide Angle Baffle

Clearly, the Wide Angle Baffle should be constructed from a lower BRDF material, and/or suspended to reduce the scattered light displacement noise.

3 MANIFOLD BAFFLE

The Manifold Baffle is located inside the manifold tube leading to the test mass near each end of the arm beam tube, as shown in Figure 8.



The baffle consists of an outer cylinder, a cone, an inner cylinder.

The Manifold Baffle catches the narrow angle scattered light from the far test mass at the opposite end of the beam tube that passes through the Beam Tube Baffles.

The Manifold Baffle should be suspended as a pendulum from vertical blade springs to provide horizontal and vertical motion attenuation.

Ideally, it should be made from a low BRDF material, such as oxidized, polished stainless steel, or a polished material surface coated with DLC material.

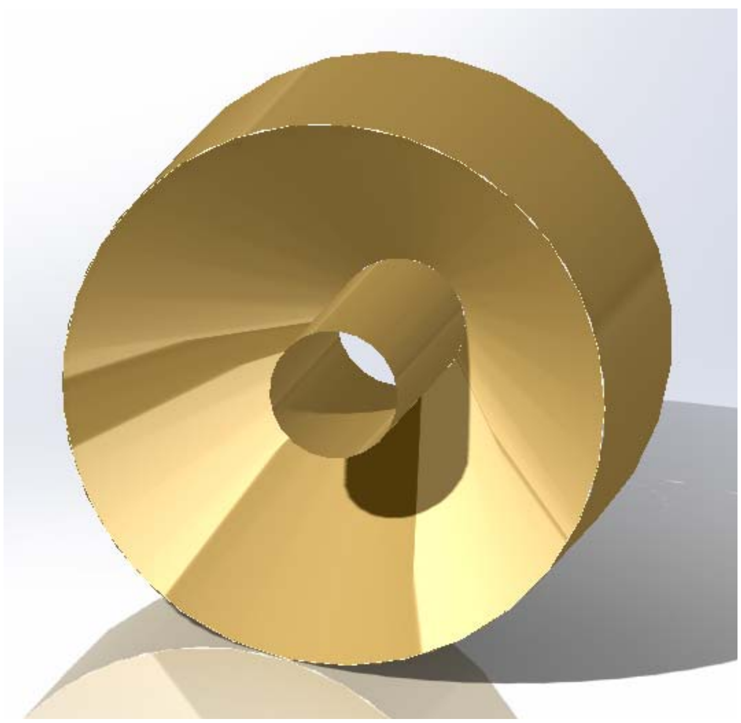


Figure 8: Manifold Baffle

The side of the baffle that faces toward the opposite end of the arm has an annular trapping region comprised of the inner cylinder and the inner surface of the cone.

3.1 Manifold/Cryopump Baffle Characteristics

Location, 37m from TM

Aperture diameter, 0.228 m

3.2 Manifold Baffle Scatter Light Calculations

Arm cavity power, W $P_a := 4 \times 10^5$

laser wavelength, m $\lambda := 1.064 \cdot 10^{-6}$

wave number, m^-1 $k := 2 \cdot \frac{\pi}{\lambda}$

$k = 5.905 \times 10^6$

ITM beam size, m $w_{itm} := 0.035064$

ETM beam size, m $w_{etm} := 0.039983$

IFO waist size, m $w_{ifo} := 0.0147$

solid angle of IFO mode, sr $\Delta\Omega_{ifo} := \frac{\lambda^2}{\pi \cdot w_{ifo}^2} = 1.668 \times 10^{-9}$

Transfer function @ 100 Hz, ITM HR $TF_{itmhr} := 1 \cdot 10^{-9}$

IFO arm length, m $L_{arm} := 3000$

PSL laser power, W $P_{psl} := 50$

Minimum strain detectivity @ 100 Hz, /rt HZ $h_{min} := 3.95894e\text{-}24$

Minimum displacement detectivity @ 100 Hz, m/rt Hz $D_{min100} := 3.95894e\text{-}24 L_{arm}$

$D_{min100} = 1.188 \times 10^{-20}$

seismic displacement @ 100 HZ, m/rt HZ $x_g := 9 \cdot 10^{-11}$

radius of manifold aperture, m $R_{mb} := 0.114$

radius of beam tube baffle aperture, m

$R_{btb} := 0.175$

manifold baffle motion attenuation @ 100 HZ, m/rt HZ $A_{mb} := 1$

half-angle from centerline to Rmb, rad $\theta_{mb} := \frac{R_{mb}}{L_{arm}}$

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

half-angle from centerline to Rmb, rad $\theta_{mb} = 3.8 \times 10^{-5}$

half-angle from centerline to Rbt, rad

power incident on manifold baffle, W $P_{mb} := P_a \cdot \int_{\theta_{mb}}^{\theta_{bt}} 2 \cdot \pi \cdot \theta \cdot BRDF_1(\theta)\, d\theta$

$P_{mb} = 4.707$

power loss fraction from COC to manifold baffle $\theta_{bt} := \frac{R_{btb}}{L_{arm}} = 5.833 \times 10^{-5}$

BRDF oxidized steel, 57 deg inc.

large angle BRDF, sr^-1 $BRDF_{baf} := 0.03$

number of manifold baffles $N_{mb} := 4$

Power Scattered into IFO

$$P_{mbsifo} := \sqrt{N_{mb}} \cdot P_{mb} \cdot BRDF_{baf} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L_{arm}^{2}} \cdot BRDF_1\left(\theta_{mb}\right) \cdot \Delta\Omega_{ifo}$$

displacement noise @ 100 Hz, m/rtHz

$$P_{mbsifo} = 1.361\times 10^{-17}$$

$$DN_{mb} := TF_{itmhr}\cdot\left(\frac{P_{mbsifo}}{P_{psl}}\right)^{0.5}\cdot x_g\cdot A_{mb}\cdot 2\cdot k = 5.545\times 10^{-22}$$

$$D_{min100} = 1.188\times 10^{-20}$$

fractional power loss through ETM manifold baf aperture

$$PL_{mb} := e^{-2\cdot\left(\frac{R_{mb}}{w_{etm}}\right)^2}$$

$$PL_{mb} = 1.529\times 10^{-7}$$

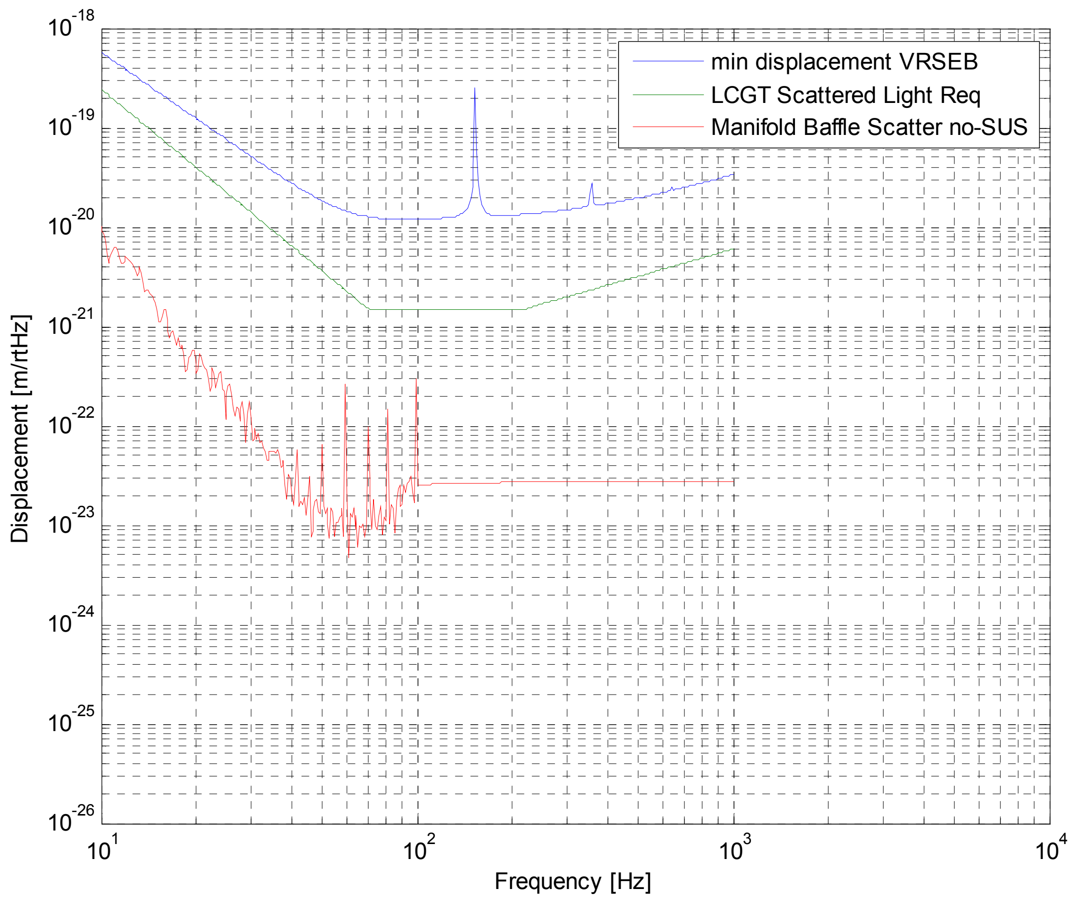


Figure 9: Manifold Baffle Displacement Noise

4 BEAM TUBE BAFFLE

A ZEMAX model of the arm cavity baffle is shown in the figure below.

The inside diameter of the hole in the baffle sets the root diameter for the serrated edge which extends inward into the hole beyond the root diameter.

A figure from Thorne's document (:LIGO T940063-00, Thorne) describing the serrated edge is shown in Figure 14. The peaks or valleys of the baffle serrations should be random in height by >4.5 mm in the vertical plane (5.5mm in the plane of the baffle). The serrated edge is necessary to reduce the coherent amplification of the edge-scattered light from the baffle into the IFO mode at the end mirror.

It is not necessary to suspend the beam tube baffles.

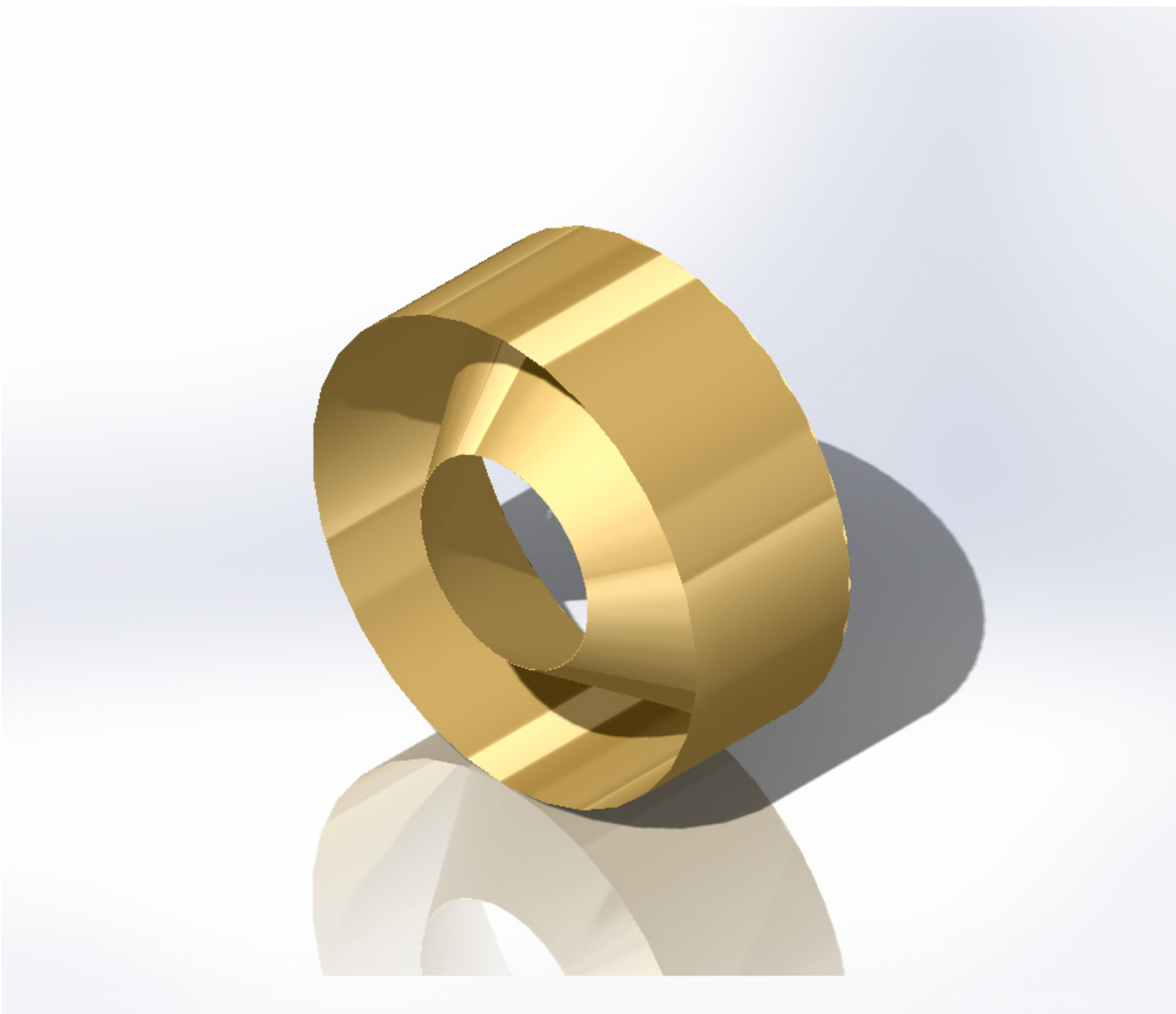


Figure 10: ZEMAX model of Beam Tube Baffle

4.1 Beam Tube Baffle Spacing Within the Beam Tube

The main function of the Beam Tube Baffle is to shield the beam tube surface from the line of sight of any direct scattered ray from the TM. The baffles would have their conical shape facing toward the nearest TM so as to trap any scattered light from the TM HR surface that impinges on the baffle.

The diameter of the Manifold Baffle and its position from the TM determines the location where the extreme ray from the TM will hit the beam tube. The 1st Beam Tube Baffle was placed at the location where the extreme ray hits the Beam Tube Baffle 40 mm away from the inside surface of the beam tube; that ensures that the view of the beam tube surface from the TM is blocked.

The 2nd Beam Tube Baffle is placed at the position where the extreme ray passing through the 1st Beam tube Baffle hits the 2nd Beam Tube Baffle 40 mm away from the inside surface of the beam tube. All succeeding BT baffles are placed using the same method as for the 1st BT baffle.

The 6th and final BT baffle was placed approximately at the middle of the beam tube.

Another sequence of 6 baffles is placed in the opposite end of the beam tube, with the same distances from the opposite TM.

The placement of the baffles was determined graphically; the Manifold Baffle and the 1st Beam Tube Baffle are shown in the figure below.

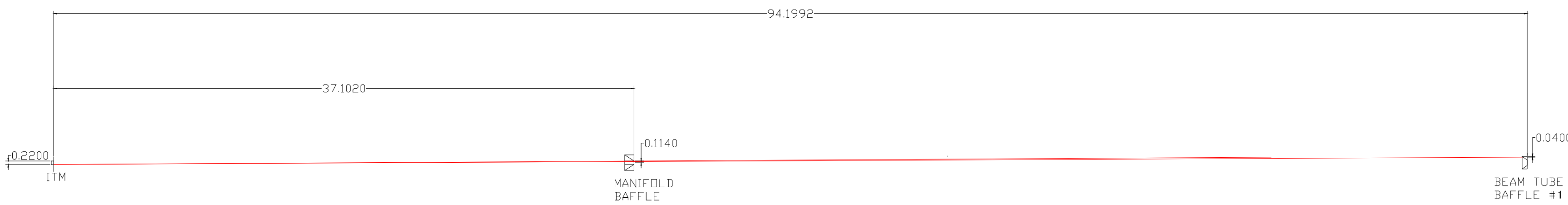


Figure 11: Location of 1st Beam Tube Baffle

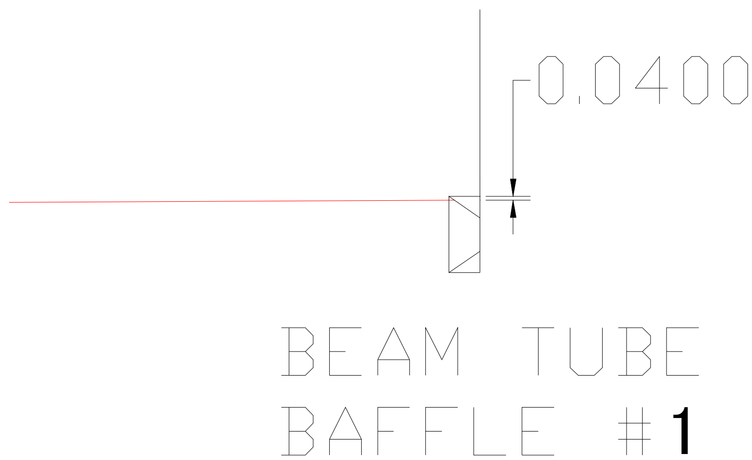


Figure 12: Detail of Extreme Ray Hitting Baffle #1

Table 1: Beam Tube Baffle Locations

Baffle Type	Baffle Number	Distance from TM, m
Manifold		37.0
Beam Tube	1	94.2
Beam Tube	2	155.3
Beam Tube	3	418.8
Beam Tube	4	690.6
Beam Tube	5	1138.8
Beam Tube	6	1480

The height of the Beam Tube Baffle opening from the beam tube wall is arbitrary because the position of the baffle will ensure that the view of the beam tube is blocked regardless of the diameter of the opening. The height chosen below ensures that 6 baffles will adequately obscure the wall of the team tube from the nearest TM.

height of baffle from wall, m

$$h_{bt} := 0.400\frac{1}{2} + 0.025$$

$$h_{bt} = 0.225$$

beam tube baffle radius, m

$$R_{baf} := R_{bt} - h_{bt}$$

$$R_{baf} = 0.175$$

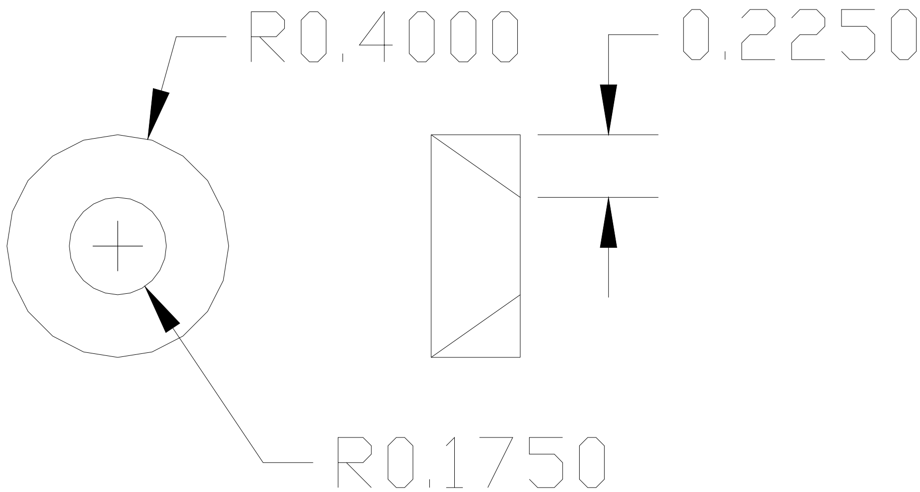


Figure 13: Beam Tube Baffle Height

This baffle size will cause negligible diffraction loss of the arm cavity beam.

fractional power loss through
beam tube baf aperture at ETM end

$$PL_{btb} := e^{-2\cdot\left(\frac{R_{baf}}{w_{etm}}\right)^2}$$

$$PL_{btb} = 2.732\times 10^{-17}$$

fractional power loss through
ETM manifold baf aperture

$$PL_{mb} := e^{-2\cdot\left(\frac{R_{mb}}{w_{etm}}\right)^2}$$

$$PL_{mb} = 8.687\times 10^{-8}$$

4.2 Beam Tube Baffle Serration Height

The baffle will have random serrations that extend from the inside diameter of the baffle toward the center. The height of the serrations should be > 4.5 mm, as shown in the calculations below, so that the sawtooth extends across >2 Fresnel zones.

see Thorne, T950101, p9

width of Fresnel zone for baffle at center of beam tube, m

$$w_{0.5L} := \frac{\lambda \cdot L_{arm}}{8 \cdot R_{baf}}$$

$$w_{0.5L} = 2.285 \times 10^{-3}$$

height of serration, m

$$\Delta h_{ser} := 2 \cdot w_{0.5L}$$

$$\Delta h_{ser} = 4.57 \times 10^{-3}$$

4.3 Beam Tube Baffle Displacement Noise Calculations

4.3.1 Scattered Light Displacement Noise Numerical Parameters

The displacement noise calculations use the following parameters:

Arm cavity power, W	$P_a := 4 \times 10^5$
laser wavelength, m	$\lambda := 1.064 \cdot 10^{-6}$
wave number, m^-1	$k := 2 \cdot \frac{\pi}{\lambda}$
	$k = 5.905 \times 10^6$
ITM beam size, m	$w_{itm} := 0.03506$
ETM beam size, m	$w_{etm} := 0.03998$
IFO waist size, m	$w_{ifo} := 0.014$
solid angle of IFO mode, sr	$\Delta\Omega_{ifo} := \frac{\lambda^2}{\pi \cdot w_{ifo}^2} = 1.668 \times 10^{-9}$
IFO arm length, m	$L_{arm} := 3000$
PSL laser power, W	$P_{psl} := 50$
Transfer function @ 100 Hz, ITM HR	$TF_{itmhr} := 1.1 \cdot 10^{-9}$
Minimum strain detectivity @ 100 Hz, /rt HZ	$h_{min} := 3.95894e\text{-}24$
Minimum displacement detectivity @ 100 Hz, m/rt Hz	$D_{min100} := 3.95894e\text{-}24 L_{arm}$
	$D_{min100} = 1.188 \times 10^{-20}$
seismic displacement @ 100 HZ, m/rt HZ	$x_g := 3 \cdot 10^{-12}$
beam tube baffle BRDF, sr^-1	$BRDF_{bt} := 0.03$

number of beam tube baffles $N_{bt} := 6$

radius of beam tube, m $R_{bt} := 0.4$

radius of manifold baf aperture, m $R_{mb} := 0.112$

beam tube baffle motion attenuation @ 100 HZ, m/rt HZ $A_{bt} := 1$

distance to near baffle, m $l_2 := 46.875$

distance to far baffle, m $l_1 := 3000$

half-angle from centerline to near baffle, rad $\theta_2 := \frac{R_{bt}}{l_2}$ $\theta_2 = 8.533\times 10^{-3}$

half-angle from centerline to far baffle, rad $\theta_1 := \frac{R_{bt}}{l_1}$ $\theta_1 = 1.333\times 10^{-4}$

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

BRDF exponent $\gamma := 2\cdot 1.23597$

$\gamma = 2.472$

BRDF scale factor $\alpha := \frac{2755.12}{\left(1 + 8.50787\cdot 10^{8}\right)^{1.23597}}$

$\alpha = 2.53\times 10^{-8}$

break-over angle, rad $\theta_{bo} := \sqrt{\frac{1}{\left(8.50787\cdot 10^{8}\right)}}$

$\theta_{bo} = 3.428\times 10^{-5}$

4.3.2 Beam Tube Baffle Diffraction Noise from Vibrating Edge

4.3.2.1 Beam Tube Baffle Diffraction Noise without Serrations

The diffraction noise caused by the vibration of the beam tube baffles with no serrations was calculated by Thorne for an inverse square law BRDF scattering function of the TM mirror. The diffraction noise arises because the radial vibration of the baffle modulates the scattered light that passes between the two TM mirrors at opposite ends of the beam tube. Thorne calculated the diffraction from unserrated baffles, assuming an inverse square law scattering BRDF by the TM mirrors.

$$BRDF_{TM} := \frac{\alpha}{\theta^2}$$

Thorne'sdiffraction noise eqtn.
without serrations

$$D_{diffthorneno} := \frac{\alpha \cdot \lambda \cdot A_{bt} \cdot x_g \cdot \sqrt{N_{bt}}}{\sqrt{2} \cdot L_{arm} \cdot R_{baf}} \cdot L_{arm}$$

$$D_{diffthorneno} = 8.012 \times 10^{-25}$$

4.3.2.2 Beam Tube Baffle Diffraction Noise Reduction with Uniform Serrations

According to Thorne, the edges of the baffle should be made irregular to avoid the coherent addition of diffracted light from the perimeter of the baffle opening. This can be accomplished by making random peaks and valleys in the form of a sawtooth pattern along the edge of the hole, as specified in the document E950083-B, Science Requirements for the LIGO Beam Tube Baffles, by A. Lazzarini. The worst diffraction noise occurs from the baffles near the center of the beam tube, where the Fresnel zone spacing is greatest.

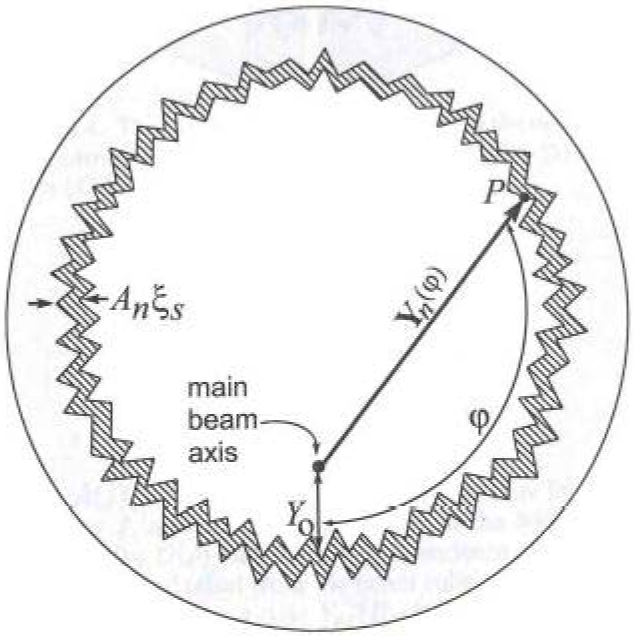


FIG. 3. Diagram, in the plane of baffle n, depicting the geometry used in a phase-coherent computation of diffraction noise.

Figure 14: Description of Serrated Baffle Edge from Thorne

The reduction in edge diffraction noise resulting from using uniform serrations was calculated by Thorne; and with a centered beam for the baffles near the center of the beam tube, the noise reduction is shown in the following.

Relative reduced distance of baffle

$$\beta_n := \frac{4 \cdot L_n \cdot (L_{arm} - L_n)}{L_{arm}^2}$$

$$Sum\beta sq := \beta_1^2 + \beta_2^2 + \beta_3^2 + \beta_4^2 + \beta_5^2 + \beta_6^2$$

reduction in diffracted light noise due to uniformly serrated baffles

$$f_{ser} := \frac{\sqrt{2} \cdot \lambda \cdot L_{arm}}{8 \cdot \pi \cdot R_{baf} \cdot \Delta h_{ser}} \cdot \left(\frac{1}{N_{bt}} \cdot Sum\beta sq \right)^{0.5}$$

$$f_{ser} = 0.15$$

4.3.2.3 Beam Tube Baffle Diffraction Noise Reduction with Random Serrations

An additional reduction in diffracted light noise will occur if the serrations are randomized, both in pitch and height.

additional reduction in diffracted light noise due to random serrations

$$f_{ran} := \left(\frac{\sqrt{\frac{\lambda \cdot L_{arm}}{4}}}{2 \cdot \pi \cdot R_{baf}} \right)^{0.5}$$

$$f_{ran} = 0.16$$

4.3.2.4 Total Beam Tube Baffle Diffraction Noise with Random Serrations

Total diffracted light noise, Thorne, m/rtHz

$$D_{diffthorne} := D_{diffthorneno} \cdot f_{ser} \cdot f_{ran}$$

$$D_{diffthorne} = 1.932 \times 10^{-26}$$

4.3.2.5 Beam Tube Baffle Diffraction Noise with General BRDF Law

Smith extended Thorne's diffraction equation (4) T950101 for a general exponential BRDF scattering law with exponent gamma,

BRDF in exponential range

$$BRDF_1(\theta) := \frac{\alpha}{\theta^{\gamma}}$$

Using the following assumptions:

assumptions

$$Y_n := R_{baf}$$

$$\theta := \frac{R_{baf}}{l_n}$$

$$r := l_n$$

the diffraction displacement noise takes the following form:

$$D_{diffsmith}(\gamma) := \frac{\alpha \cdot \lambda \cdot A_{bt} \cdot x_g \cdot \sqrt{N_{bt}}}{2^{0.5+2-\gamma} \cdot L_{arm}^{\,2-\gamma} \cdot R_{baf}^{\,\gamma-1}} \cdot f_{ser} \cdot f_{ran}$$

And, for the gamma = 2.472 power law of the LIGO pathfinder mirrors, the displacement noise, m/rtHz, at 100 Hz is

$$D_{diffsmith}(2.472) = 2.673 \times 10^{-24}$$

4.3.3 Baffle Surface Scatter Noise

4.3.3.1 Surface BRDF

The Beam Tube Baffle is constructed of polished oxidized steel with the first surface inclined at an incidence angle 55 deg. The measured BRDF is < 0.03 sr^{-1}; the scattered light noise can be reduced considerably by coating the surface with DLC coating.

The power scattered by the baffles into the mode of the IFO and the resulting displacement noise is calculated using Smith’s transfer function formalism.

power scattered into IFO mode, W

$$P_{btbsiforeal} := N_{bt} \cdot P_a \cdot 2 \cdot \pi \cdot \frac{\lambda^2}{R_{bt}^{\,2}} \cdot BRDF_{bt} \cdot \int_{\theta_1}^{\theta_2} \theta^3 \cdot BRDF_1(\theta)^2 \, d\theta$$

$$P_{btbsiforeal} = 9.008 \times 10^{-18}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{btbaf} := TF_{itmhr} \cdot \left(\frac{P_{btbsifo}}{P_{psl}}\right)^{0.5} \cdot Cos\Phi_{ave} \cdot A_{bt} \cdot x_g \cdot 2 \cdot k$$

$$DN_{btbaf} = 1.201 \times 10^{-23}$$

This agrees with Thorne's result when it is extended to include an arbitrary BRDF scattering power law.

beam tube baffle scattered light strain generalized for γ unequal to 2 (from ref:LIGO T940063-00,Thorne)

BRDF exponent $\gamma := 2\cdot 1.2359$

$\gamma = 2.472$

Average slow phase variation of scattering surface $Cos\Phi_{ave} := \sqrt{\frac{1}{2}}$

$$h_t := \left[\frac{N_{bt}}{4}\cdot 4\cdot\pi\cdot\alpha^2 BRDF_{bt}\cdot\left(\frac{1}{l_2^{\,4-2\cdot\gamma}} - \frac{1}{l_1^{\,4-2\cdot\gamma}}\right)\cdot\frac{1}{(4-2\cdot\gamma)}\right]^{0.5}\cdot A_{bt}\cdot\frac{\lambda}{R_{bt}^{\,\gamma-1}}\cdot\frac{Cos\Phi_{ave}\cdot\sqrt{2}\cdot x_g}{L_{arm}}$$

$h_t = 3.445\times 10^{-27}$

displacement noise (Thorne)

$DN_{btbafth} := L_{arm}\cdot h_t$

$DN_{btbafth} = 1.033\times 10^{-23}$

4.3.4 Summary of Beam Tube Baffle Displacement Noise

A summary of the Beam Tube Baffle displacement noise spectrum is shown in the figure below.

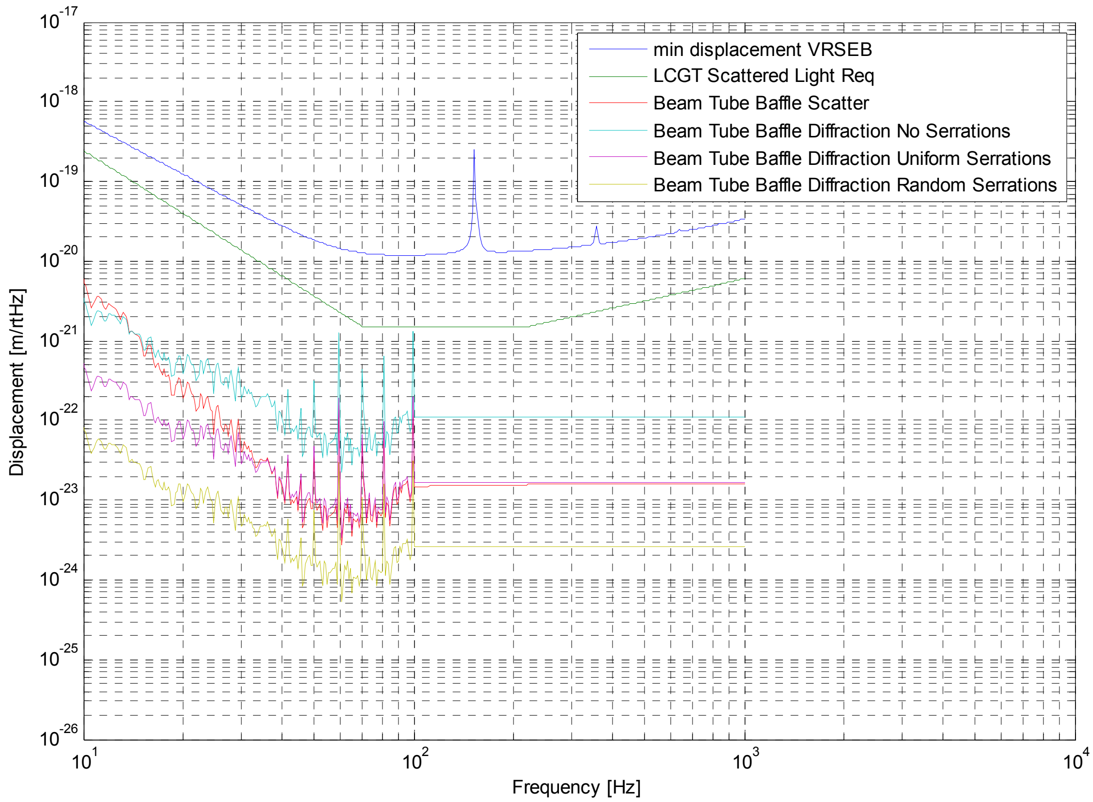


Figure 15: Beam Tube Baffles Scattered Light Displacement Noise

5 INTERFACE CONTROL DOCUMENT

.

.