LIGO Laboratory / LIGO Scientific Collaboration

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AOS SLC
BS Elliptical Baffle
Final Design

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Table of Contents

Table of Figures

Table of Tables

1 INTRODUCTION

1.1 Scope

This document provides the final design for the BS Elliptical Baffle, with the Final Design Review Checklist

1.1.1 Final requirements – any changes or refinements from PDR?

This is a new requirement. The requirements for the BS Elliptical affle are listed in T070061 Stray Light Control Design Requirements.

Direct Requirements

Phase noise due to scattered light fields injected into the interferometer is treated as a technical noise source. Therefore, the total scattered light phase noise, expressed in equivalent displacement noise, must be < 1/10th of the quadrature sum of the suspension thermal noise and the test mass thermal noise (referred to as the SRD), as given in Figure 1 of M060056-06, Advanced LIGO Reference Design.

BS Elliptical Baffle Requirements

BS Elliptical Baffles will be placed on the HR and AR sides of the BS. They will form elliptical apertures to ensure that the overlap of the two recycling cavity beams at the BS is maximized. Their alignment accuracy will be sufficient to minimize the contrast defect.

They will block the excess arm cavity beams exiting through the ITM AR face that pass through the openings of the ITM Elliptical baffles.

1.1.2 Resolutions of action items from SLC PDR

Lower BRDF Material for Baffles
We suggest the team consider a lower-BRDF material for the more critical baffles;
and in particular, suggest looking at the electro-static frit black-enameled steel as an option
that would give better optical performance.
Ans: *The lowest BRDF material that is practical at the moment is oxidized polished stainless steel.*

1.1.3 Final Parts Lists and Drawing Package

D1200750 aLIGO, AOS, BS ELLIPTICAL BAFFLE ASSY

E1200520 BOM for BS ELLIPTICAL BAFFLE ASSY

1.1.4 Final specifications

E0900364-v8 Metal components intended for use in the Adv LIGO Vacuum System

E1100842 Specification for Mirror Finished (Super #8) Stainless Steel to be used in the LIGO Ultra-High Vacuum System

1.1.5 Final interface control documents

The mechanical and optical interfaces of the ITM ELLIPTICAL BAFFLE are described in:

D0901142-v4 AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly
D0900428-v5 AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
D0900525-v2 AdvLIGO SUS BSC2-L1, XYZ Local CS for Elliptical Baffle (ITMX,ITMY)

1.1.6 Relevant RODA changes and actions completed

Not applicable

1.1.7 Signed Hazard Analysis

E1200659 AOS SLC BS Elliptical Baffle Install Hazard Analysis

1.1.8 Final Failure Modes and Effects Analysis

Not Required

1.1.9 Risk Registry items discussed

None for this subsystem

1.1.10 Design analysis and engineering test data

See Section 3 Descriptions of Baffles and Section 4 Scattered Light Displacement Noise

1.1.11 Software detailed design

Not applicable

1.1.12 Final approach to safety and use issues

E1200659 AOS SLC BS Elliptical Baffle Install Hazard Analysis

1.1.13 Production Plans for Acquisition of Parts, Components, Materials Needed For Fabrication

E1200662 BS Elliptical Baffle Production Plan

1.1.14 Installation Plans and Procedures

E1200660 BS Elliptical Baffle Installation Procedure

1.1.15 Final hardware test plans

E1200661 BS Elliptical Baffle Fabrication and Installation Test Plan

1.1.16 Final software test plans

Not applicable.

1.1.17 Cost compatibility with cost book

See E1200662 BS Elliptical Baffle Production Plan

1.1.18 Fabrication, installation and test schedule

AOS SLC BS Elliptical Baffle	Duration	Start	Finish
BS Elliptical Baffle	**30 days**	**Mon 6/18/12**	**Fri 7/27/12**
Procure Baffles	12 days	Mon 6/18/12	Tue 7/3/12
Procure Metal Works	15 days	Mon 6/18/12	Fri 7/6/12
Procure hardware	22 days	Mon 6/18/12	Tue 7/17/12
Procure tooling	15 days	Tue 7/3/12	Mon 7/23/12
Have parts cleaned and oxidized	10 days	Wed 7/4/12	Tue 7/17/12
ship baffle parts to Observatory	5 days	Wed 7/18/12	Tue 7/24/12
ship metal parts to Observatory	3 days	Wed 7/18/12	Fri 7/20/12
ship tooling to Observatory	3 days	Tue 7/24/12	Thu 7/26/12
Clean & Bake parts - Class A	5 days	Mon 7/23/12	Fri 7/27/12
Clean & Bake tooling - Class B	1 day	Fri 7/27/12	Fri 7/27/12
Ready for Install	0 days	Fri 7/27/12	Fri 7/27/12

L1 Installations	Duration	Start	Finish
INS L1: Finalize Cartridge, AOS Baffles (BSC2)	5 days	Tue 9/18/12	Mon 9/24/12
INS L1: Install Cartridge/CO2P & Align (BSC2)	10 days	Tue 9/25/12	Mon 10/8/12

1.1.19 Lessons Learned Documented, Circulated

The baffles will be constructed of oxidized polished stainless steel to avoid shedding of the porcelain surface.

1.1.20 Problems and concerns

There are presently no known problems or concerns with the BS Elliptical baffle.

1.2 Applicable Documents

T070303 Arm Cavity Finesse for aLIGO

T070247 aLIGO ISC Conceptual Design

E0900364-v8 LIGO Metal in Vacuum

T060073-00 Transfer Functions of Injected Noise

T070061-v2 Stray light Control Design Requirements

T0900269-v2 Stray Light Control (SLC) Preliminary Design

E1200661 BS Elliptical Baffle Fabrication and Installation Test Plan
E1200660 BS Elliptical Baffle Installation Procedure
E1200659 AOS SLC BS Elliptical Baffle Install Hazard Analysis
E1200662 BS Elliptical Baffle Production Plan
T070061 AOS: Stray Light Control (SLC) Design Requirements
D0900428-v5 AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
D0901142-v4 AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly

T1000090 Advanced LIGO Baffle Design using SIS

2 BAFFLE DESCRIPTIONS

2.1 FUNCTION

2.1.1 BS ELLIPTICAL BAFFLE

The BS Elliptical Baffles form elliptical apertures of 210 mm horizontal diameter and 260 mm vertical diameter on the X and Y arms of the recycling cavity, which ensure that the overlap of the two recycling cavity beams at the BS is maximized. They block the excess arm cavity beams exiting through the ITM AR face that pass through the openings of the ITM Elliptical baffles.

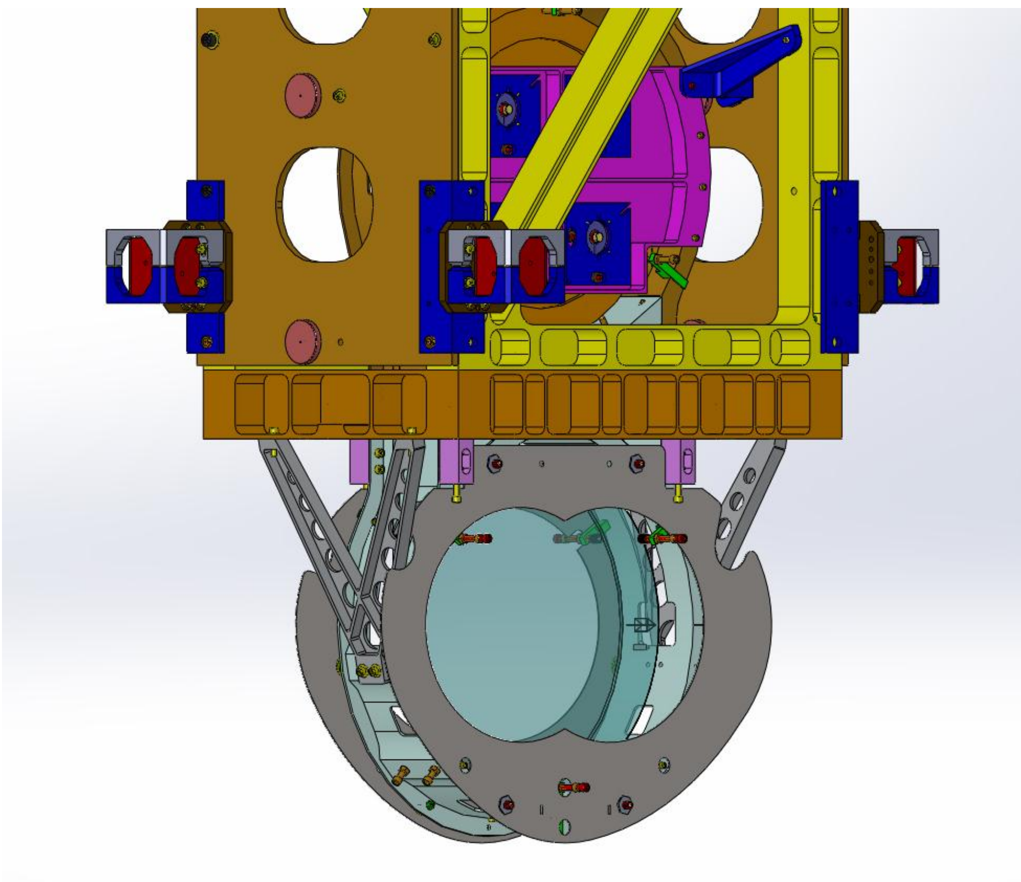

Figure 1: Model of BS Elliptical Baffles Installed on the BS SUS

2.2 H1 & L1 IFO ZEMAX LAYOUT

The H1 & L1 IFO ZEMAX layout of BSC2 is shown in Figure 2.

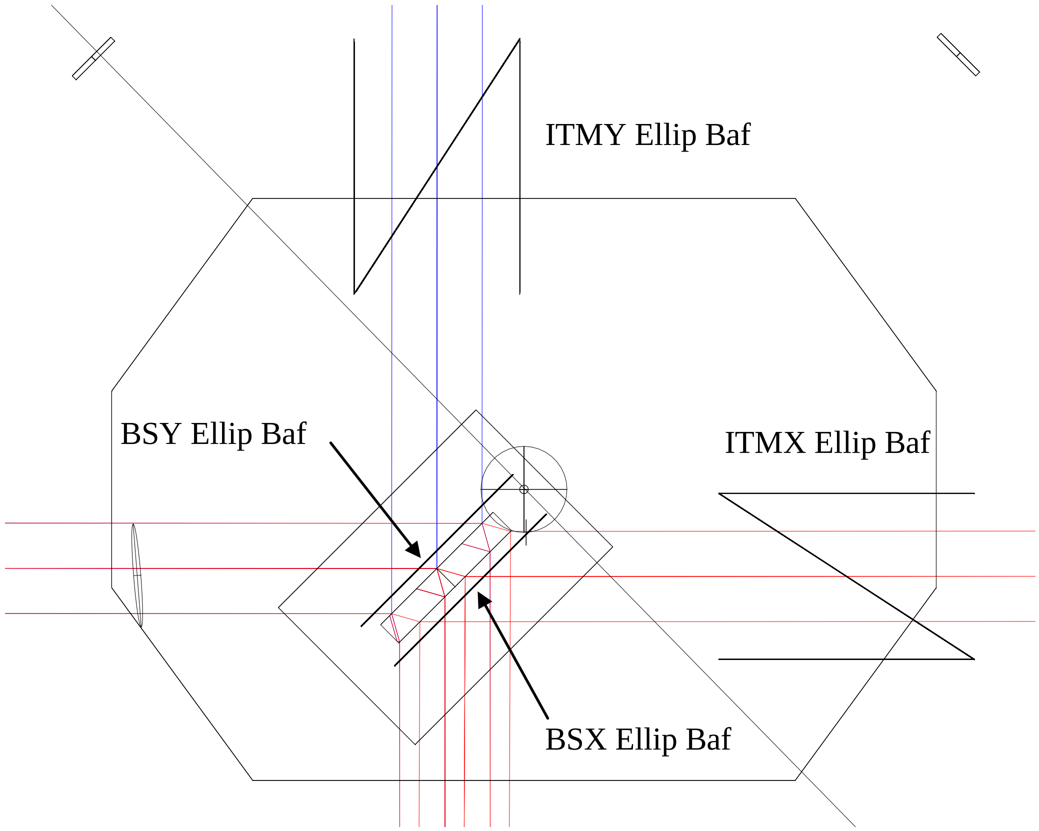

Figure 2: ZEMAX Layout of BSC2 with BS Elliptical Baffles

3 DESCRIPTION OF BAFFLE

3.1 ATTACHMENT

The BS Elliptical Baffle is attached to the BS SUS lower frame, as shown in Figure 1.

The internal resonances of the baffle have not been measured (TBD)

3.2 BS ELLIPTICAL BAFFLE CHARACTERISTICS

The characteristics of the ITM Elliptical Baffle are shown in Table 1.

Table 1: BS Elliptical Baffle Characteristics

Parameter	Value

Parameter	Value
Location	Mounted to BS SUS in BSC2
Aperture diameter	210 mm horizontal, 260 mm vertical
Material	Oxidized polished stainless steel
BRDF	<0.03 sr^-1
Weight (both baffles plus hardware)	5 lbs

3.3 OPTICAL INTERFACES

The BS Elliptical Baffles are placed in the X and Y arm signal recycling cavities to mitigate the finite size of the BS mirror and produce identical and symmetrical beam shapes at the recombining beam splitter—see T1000090 Advanced LIGO Baffle Design using SIS. The optimum aperture size of the BS Elliptical Baffle was determined to be 210mm horizontal by 230 mm vertical. The baffles must be aligned with the optical centerline of the power recycling cavity beams in order to minimize the contrast defect of the interfering cavity beams, and to minimize the loss of power recycling cavity.

3.3.1 Effect of Baffle Misplacement

Offsetting the BS Elliptical Baffle from the recycling cavity beam center line causes an increase in contrast defect at the dark port. The baffles will be aligned within 0.5mm of the beam centerline in order to limit the contrast defect to < 18ppm (see T1000090 Advanced LIGO Baffle Design using SIS).

4 SCATTERED LIGHT DISPLACEMENT NOISE

4.1 Scattered Light Requirement

A DARM signal is obtained when the differential arm length is modulated as a result of a gravity wave strain. The DARM signal was calculated in reference, T060073-00 Transfer Functions of Injected Noise, and is defined by the following expression:

$$V_{signal} := DARM \cdot L \cdot h_{SRD} \cdot \sqrt{P_0}$$

Where L is the arm length, hSRD is the minimum gravity wave strain spectral density requirement, P0 is the input laser power into the IFO, and DARM is the signal transfer function.

In a similar manner, an apparent signal (scattered light noise) occurs when a scattered light field with a phase shift is injected into the IFO at some particular location, e.g. through the back of the ETM mirror. The scattered light noise is defined by the following expression:

$$V_{noise} := SNXXX \cdot \delta_{SN} \cdot \sqrt{P_{SNi}}$$

P_{SNi} is the scattered light power injected into the IFO mode, δ_{SN} is the phase shift of the injected field, and SNXXX is the noise transfer function for that particular injection location.

The phase shift spectral density of the injected field due to the motion of the scattering surface is given by

$$\delta_{SNi} := \frac{4 \cdot \pi \cdot x_S}{\lambda}$$

where x_s is the spectral density of the longitudinal motion of the scattering surface.

In general, the different scattering sources are not coherent and must be added in quadrature. The requirement for total scattered light displacement noise can be stated with the following inequality:

$$\sqrt{\sum_{i=1}^{n} \left(\frac{SNXXX}{DARM} \cdot \frac{4 \cdot \pi \cdot x_S}{\lambda} \cdot \sqrt{\frac{P_{SNi}}{P_0}} \right)^2} < \frac{1}{10} \cdot L \cdot h_{SRD}$$

The SNXXX/DARM scattered light noise transfer function ratios for various injection locations within the IFO are shown in Figure 3: Scattered Light Noise Transfer Functions.

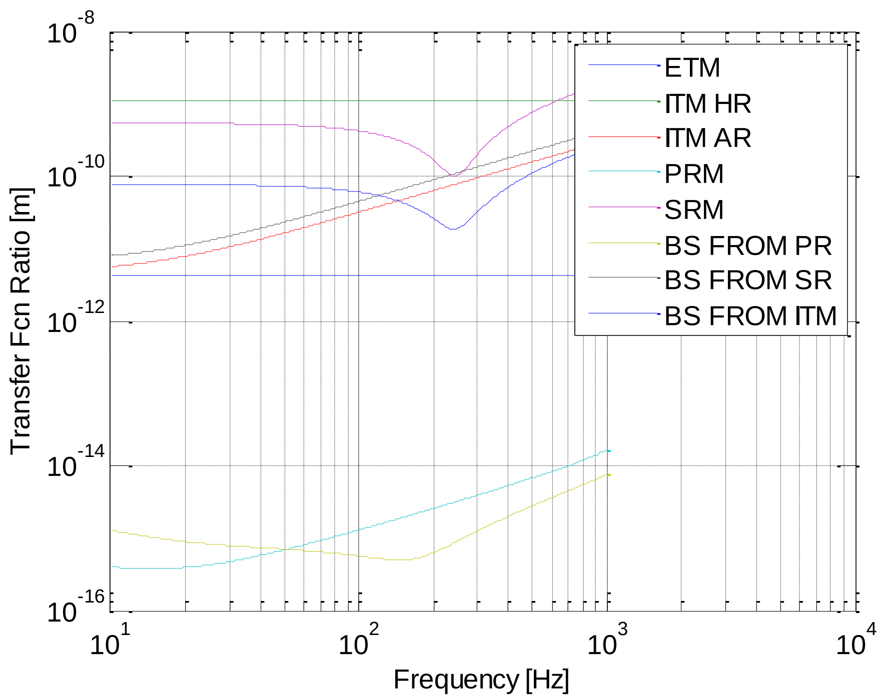

Figure 3: Scattered Light Noise Transfer Functions

4.2 Scattered Light Parameters

BRDF of ellip baf, sr^-1	$BRDF_{ellbaf} := 0.03$
Motion of BS frame @ 100 Hz, m/rtHz	$x_{sus} := 3.1 \cdot 10^{-14}$
laser wavelength, m	$\lambda := 1.064 \cdot 10^{-6}$
wave number, m^-1	$k := 2 \cdot \frac{\pi}{\lambda}$ $\quad k = 5.9052 \times 10^{6}$
Transfer function @ 100 Hz, ITM AR	$TF_{itmar} := 3.16 \cdot 10^{-11}$
ITM beam radius, m	$w_{itm} := 0.05316$
IFO waist size, m	$w_{ifo} := 0.012$
transformed beam waist after ITM AR surface	$w_{itmar0} := 0.00834$
effective scattering solid angle	$\Delta\omega_{effbsellipbaf4pt} := 3.507 \times 10^{-10}$
vertical aperture in ITM ellip baf, m	$r_{itmellipy} := 0.13$
horizontal aperture in ITM ellip baf, m	$r_{itmellipx} := 0.11$
vertical aperture in BS ellip baf, m	$r_{bsellipy} := 0.1$
horizontal aperture in BS ellip baf, m	$r_{bsellipx} := 0.10$
radius of ITM, m	$r_{itm} := 0.17$

Ref. T070247

Transmissivity of ITM HR	$T_{itmhr} := 0.014$
input laser power, W	$P_{psl} := 125$
arm cavity gain	$G_{ac} := 13000$
arm cavity power, W	$P_a := \frac{P_{psl}}{2} \cdot G_{ac}$ $\quad P_a = 8.125 \times 10^{5}$

Ref. Hiro e-mail 8/29/11

power in power recycling cavity arm, W $P_{rca} := \frac{P_a \cdot T_{itmhr}}{4}$ $P_{rca} = 2.8438 \times 10^3$

Gaussian power parameter in recycling cavity $P_{0rc} := P_{rca}$

Power recycling cavity gain $G_{rc} := \frac{2 \cdot P_{rca}}{P_{psl}}$ $G_{rc} = 45.5$

4.2.1 BRDF of Baffle Surfaces

The baffle surfaces are oxidized polished stainless steel, with a measured BRDF < 0.03 sr^-1 @ 45 deg incidence angle.

4.2.2 BSC Seismic Motion

The motion spectrum of the ISI Optical Platform is shown in Figure 4. It is assumed that the BS suspension and the BS Elliptical Baffle have the same motion spectrum.

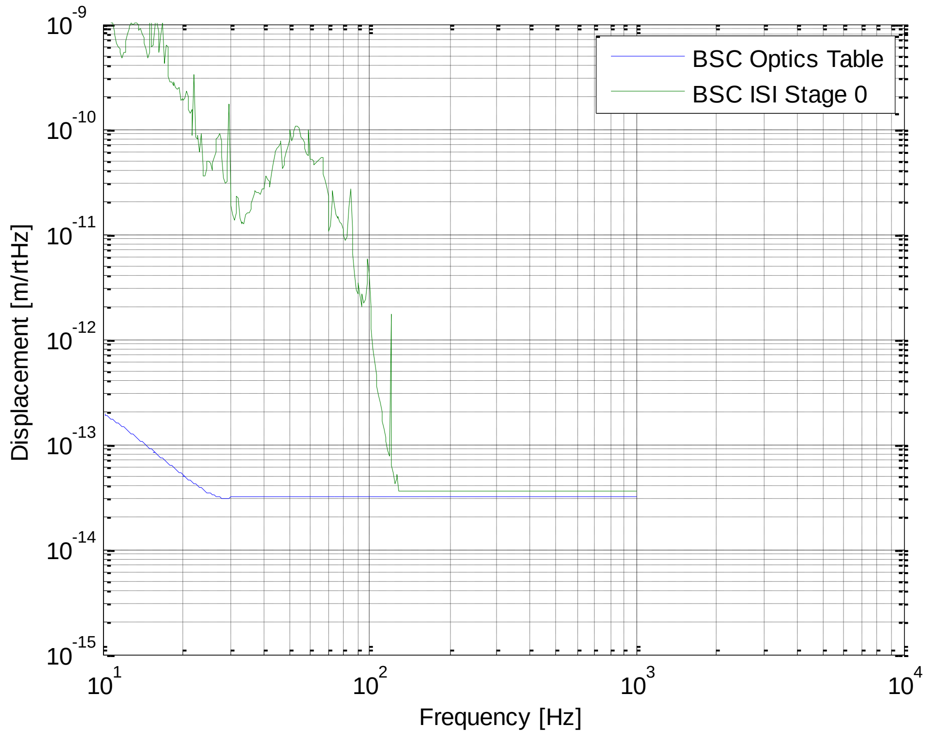

Figure 4: BSC ISI Optics Table Seismic Motion and ISI Stage 0, m/rtHz

4.2.3 BS Elliptical Baffle Scatter

Note: See BS Ellip Baf scatter overlap integral.xmcd for the scatter coupling calculation.

effective scattering solid angle

$$\Delta\omega_{effbsellipbaf4pt} := 3.507\times 10^{-10}$$

exitance function from ITM, W/m^2

$$I_{itmarm}(x,y) := 2\cdot\frac{4\cdot P_{0rc}}{\pi\cdot w_{itm}^{2}}\cdot e^{-2\cdot\left(\frac{x^2+y^2}{w_{itm}^{2}}\right)}$$

arm power exiting from ITMAR passing through itm elliptical baffle, W

$$P_{itmaritmellbaf} := 4\cdot\int_{0}^{r_{itmellipy}}\int_{0}^{r_{itmellipx}\cdot\sqrt{1-\frac{y^2}{r_{itmellipy}^{2}}}} I_{itm}(x,y)\,dx\,dy$$

$$P_{itmaritmellbaf} = 1.1374\times 10^{4}$$

arm power exiting from ITMAR passing through bs elliptical baffle, W

$$P_{itmarbsellbaf} := 4\cdot\int_{0}^{r_{bsellipy}}\int_{0}^{r_{bsellipx}\cdot\sqrt{1-\frac{y^2}{r_{bsellipy}^{2}}}} I_{itm}(x,y)\,dx\,dy$$

$$P_{itmarbsellbaf} = 1.1373\times 10^{4}$$

Power hitting BS baffle, W

$$P_{bsbaf} := P_{itmaritmellbaf} - P_{itmarbsellbaf}$$

$$P_{bsbaf} = 1.0931$$

BS ELLIPTICAL Baffle Scatter

Power scattered into IFO mode
from both arms, W

$$P_{bsellbafs} := \sqrt{2} \cdot P_{bsbaf} \cdot BRDF_{ellbaf} \cdot \Delta\omega_{effbsellipbaf4pt}$$

$$P_{bsellbafs} = 1.6264 \times 10^{-11}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{bsellbaf} := TF_{itmar} \cdot \left(\frac{P_{bsellbafs}}{P_{psl}} \right)^{0.5} \cdot x_{sus} \cdot 2 \cdot k$$

$$DN_{bsellbaf} = 4.1733 \times 10^{-24}$$

5 BAFFLE CLIPPING NOISE

The BS Elliptical Baffle is attached to the BS SUS and as a result will vibrate laterally. The effect of the lateral motion on the modulation of the DARM signal was investigated and the results are presented in G1200467 ITM Elliptical Baffle: Clipping Noise. The results show that the lateral motion will cause a negligible DARM noise.

6 INTERFACE CONTROL DOCUMENT

The mechanical and optical interfaces of the BS Elliptical Baffle are described in the following documents.

D0900428-v5 AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
D0900525-v2 AdvLIGO SUS BSC2-L1, XYZ Local CS for Elliptical Baffle (ITMX,ITMY)
D0901142-v4 AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly