*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO- T1200313-v3 *LIGO* 6/10/13

AOS SLC

BS Elliptical Baffle

Final Design

Michael Smith, Lisa C. Austin, Kurt Buckland

Distribution of this document:

LIGO Scientific Collaboration

This is an internal working note

of the LIGO Laboratory.

|  |  |
| --- | --- |
| **California Institute of Technology****LIGO Project – MS 18-34****1200 E. California Blvd.****Pasadena, CA 91125**Phone (626) 395-2129Fax (626) 304-9834E-mail: info@ligo.caltech.edu | **Massachusetts Institute of Technology****LIGO Project – NW22-295****185 Albany St****Cambridge, MA 02139**Phone (617) 253-4824Fax (617) 253-7014E-mail: info@ligo.mit.edu |
| **LIGO Hanford Observatory****P.O. Box 159****Richland WA 99352**Phone 509-372-8106Fax 509-372-8137 | **LIGO Livingston Observatory****P.O. Box 940****Livingston, LA 70754**Phone 225-686-3100Fax 225-686-7189 |

http://www.ligo.caltech.edu/

**Table of Contents**

Table of Tables 4

1 INTRODUCTION 5

1.1 Scope 5

1.1.1 Final requirements – any changes or refinements from PDR? 5

Direct Requirements 5

BS Elliptical Baffle Requirements 5

1.1.2 Resolutions of action items from SLC PDR 5

Lower BRDF Material for Baffles 5

1.1.3 Final Parts Lists and Drawing Package 5

1.1.4 Final specifications 5

1.1.5 Final interface control documents 5

1.1.6 Relevant RODA changes and actions completed 6

1.1.7 Signed Hazard Analysis 6

1.1.8 Final Failure Modes and Effects Analysis 6

1.1.9 Risk Registry items discussed 6

1.1.10 Design analysis and engineering test data 6

1.1.11 Software detailed design 6

1.1.12 Final approach to safety and use issues 6

1.1.13 Production Plans for Acquisition of Parts, Components, Materials Needed For Fabrication 6

1.1.14 Installation Plans and Procedures 6

1.1.15 Final hardware test plans 6

1.1.16 Final software test plans 6

1.1.17 Cost compatibility with cost book 6

1.1.18 Fabrication, installation and test schedule 7

1.1.19 Lessons Learned Documented, Circulated 7

1.1.20 Problems and concerns 7

1.2 Applicable Documents 7

2 BAFFLE DESCRIPTIONS 8

2.1 FUNCTION 8

2.1.1 BS ELLIPTICAL BAFFLE 8

2.2 H1 & L1 IFO ZEMAX LAYOUT 9

3 DESCRIPTION OF BAFFLE 9

3.1 ATTACHMENT 9

3.2 BS ELLIPTICAL BAFFLE CHARACTERISTICS 9

3.3 OPTICAL INTERFACES 10

3.3.1 Effect of Baffle Misplacement 10

4 SCATTERED LIGHT DISPLACEMENT NOISE 10

4.1 Scattered Light Requirement 10

4.2 Scattered Light Parameters 12

4.2.1 BRDF of Baffle Surfaces 13

4.2.2 BSC Seismic Motion 13

4.2.3 BS Elliptical Baffle Scatter 14

5 BAFFLE CLIPPING NOISE 17

6 INTERFACE CONTROL DOCUMENT 17

 **Table of Figures**

[Figure 1: Model of BS Elliptical Baffles Installed on the BS SUS 8](#_Toc364249147)

[Figure 2: ZEMAX Layout of BSC2 with BS Elliptical Baffles 9](#_Toc364249148)

[Figure 3: Scattered Light Noise Transfer Functions 12](#_Toc364249149)

[Figure 4: BSC ISI Optics Table Seismic Motion and ISI Stage 0, m/rtHz 14](#_Toc364249150)

[Figure 5: BS Elliptical Baffle Scattered Light Displacement Noise 17](#_Toc364249151)

#  Table of Tables

[Table 1: BS Elliptical Baffle Characteristics 10](#_Toc364092532)

**CHANGE LOG**

|  |  |
| --- | --- |
| **Date, version** | **Summary of Changes** |
| 3/26/13V2 | * Added reference to [M1200268](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=94332), RODA.
* Changed the scattered light scattering solid angle p14
 |
| 6/10/13V3 | * Added reference to Hiro’s e-mail 8-20-12
* Updated SLC calculations & added figure 5
 |

# INTRODUCTION

## Scope

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

### Final requirements – any changes or refinements from PDR?

This is a new requirement. The requirements for the BS Elliptical affle are listed in [T070061](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=27791) 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](https://dcc.ligo.org/DocDB/0001/M060056/002/AdL-reference-design-v2.pdf)-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.

### 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.*

### Final Parts Lists and Drawing Package

[D1200750](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=91522) aLIGO, AOS, BS ELLIPTICAL BAFFLE ASSY

[E1200520](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=91525) BOM for BS ELLIPTICAL BAFFLE ASSY

### Final specifications

[E0900364-v8 Metal components intended for use in the Adv LIGO Vacuum System](https://dcc.ligo.org/DocDB/0006/E0900364/008/E0900364-v8%20LIGO%20Metal%20in%20Vacuum.pdf)

[E1100842 Specification for Mirror Finished (Super #8) Stainless Steel to be used in the LIGO Ultra-High Vacuum System](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=70485)

### Final interface control documents

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

[D0901142-v4](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=2759)   AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly
[D0900428-v5](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=1267)   AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
[D0900525-v2](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=1496)   AdvLIGO SUS BSC2-L1, XYZ Local CS for Elliptical Baffle (ITMX,ITMY)

### Relevant RODA changes and actions completed

*Not applicable*

### Signed Hazard Analysis

[E1200659](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93137) AOS SLC BS Elliptical Baffle Install Hazard Analysis

### Final Failure Modes and Effects Analysis

*Not Required*

### Risk Registry items discussed

*None for this subsystem*

### Design analysis and engineering test data

See Section Descriptions of Baffles and Section Scattered Light Displacement Noise

### Software detailed design

 *Not applicable*

### Final approach to safety and use issues

[E1200659](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93137) AOS SLC BS Elliptical Baffle Install Hazard Analysis

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

[E1200662](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93144) BS Elliptical Baffle Production Plan

### Installation Plans and Procedures

[E1200660](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93144) BS Elliptical Baffle Installation Procedure

### Final hardware test plans

[E1200661](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93143) BS Elliptical Baffle Fabrication and Installation Test Plan

### Final software test plans

Not applicable.

### Cost compatibility with cost book

See [E1200662](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93144) BS Elliptical Baffle Production Plan

### 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 |

### Lessons Learned Documented, Circulated

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

### Problems and concerns

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

## Applicable Documents

[T070303 Arm Cavity Finesse for aLIGO](https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=27919)

[T070247 aLIGO ISC Conceptual Design](https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=5306)

[E0900364-v8 LIGO Metal in Vacuum](https://dcc.ligo.org/DocDB/0006/E0900364/008/E0900364-v8%20LIGO%20Metal%20in%20Vacuum.pdf)

[T060073-00 Transfer Functions of Injected Noise](https://dcc.ligo.org/DocDB/0027/T060073/000/T060073-00.pdf)

[T070061-v2 Stray light Control Design Requirements](https://dcc.ligo.org/DocDB/0027/T070061/002/T070061-v2_AOS_SLC_DRD.pdf)

[T0900269-v2 Stray Light Control (SLC) Preliminary Design](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=2822)

[E1200661](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93143) BS Elliptical Baffle Fabrication and Installation Test Plan
[E1200660](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93144) BS Elliptical Baffle Installation Procedure
[E1200659](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93137) AOS SLC BS Elliptical Baffle Install Hazard Analysis
[E1200662](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=93144) BS Elliptical Baffle Production Plan
[T070061](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=27791)   AOS: Stray Light Control (SLC) Design Requirements
[D0900428-v5](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=1267)    AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
[D0901142-v4](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=2759)    AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly

[T1000090 Advanced LIGO Baffle Design using SIS](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=9376)

# BAFFLE DESCRIPTIONS

## FUNCTION

### 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 : Model of BS Elliptical Baffles Installed on the BS SUS

## H1 & L1 IFO ZEMAX LAYOUT

The H1 & L1 IFO ZEMAX layout of BSC2 is shown in Figure 1.



ITMX Ellip Baf

BSY Ellip Baf

BSX Ellip Baf

ITMY Ellip Baf

Figure : ZEMAX Layout of BSC2 with BS Elliptical Baffles

# DESCRIPTION OF BAFFLE

## 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)

## BS ELLIPTICAL BAFFLE CHARACTERISTICS

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

Table : BS Elliptical Baffle Characteristics

| **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 |

## 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](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=9376). 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.

Hiro Yamamoto re-stated his estimate of the position tolerance of the BS Elliptical Baffle in a recent e-mail, which is quoted here.

**The original estimation is based on the total junk power on the dark size of BS, regardless of the mode composition for the conservative estimation. The misplacement will cause junk field with power populated non-central region. One reference value used in T1200137 is the power on the dark side used for control, which is 60(120W case) -100 (25W case)ppm. The contrast defect due to the misplacement is ~60ppm (high power case) x displacement in mm. So the misplacement of 1~2mm will be acceptable.**

**The signal itself is not affected by the misplacement, so the effect of the larger misplacement may make the control a little bit difficult, but will not be much.**

### 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 the horizontal direction and +/- 1mm vertically (see [M1200268](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=94332)) in order to limit the contrast defect to < 18ppm (see [T1000090 Advanced LIGO Baffle Design using SIS](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=9376)).

# SCATTERED LIGHT DISPLACEMENT NOISE

## 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:



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:



PSNi is the scattered light power injected into the IFO mode, δSN 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

where xs 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:



The SNXXX/DARM scattered light noise transfer function ratios for various injection locations within the IFO are shown in Figure 2: Scattered Light Noise Transfer Functions.



Figure : Scattered Light Noise Transfer Functions

## Scattered Light Parameters

BRDF of ellip baf, sr^-1



Motion of BS frame @ 100 Hz, m/rtHz



laser wavelength, m



wave number, m^-1





Transfer function @ 100 Hz, ITM AR



ITM beam radius, m



IFO waist size, m



transformed beam waist after ITM AR surface



solid angle of ITM AR beam waist, sr





vertical aperture in ITM ellip baf, m



horizontal aperture in ITM ellip baf, m



vertical aperture in BS ellip baf, m



horizontal aperture in BS ellip baf, m



radius of ITM, m



**Ref. T070247**

Transmissivity of ITM HR



input laser power, W





arm cavity gain





arm cavity power, W

**Ref. Hiro e-mail 8/29/11**

power in power recycling cavity arm, W





Gaussian power parameter

in recycling cavity



Power recycling cavity gain





### BRDF of Baffle Surfaces

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

### BSC Seismic Motion

The motion spectrum of the ISI Optical Platform is shown in Figure 3. 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

### BS Elliptical Baffle Scatter

The scattered light that couples into the mode of the interferometer will be estimated as the scattered light within the solid angle of the mode calculated at the ITM AR surface.

solid angle of ITM AR beam waist, sr





exitance function from ITM, W/m^2



power exiting from ITM toward elliptical

baffle, W





Power passing through the ITM elliptical baffle, W





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





Power hitting BS baffle, W





Scatter efficiency of BS Elliptical Baffle





Power scattered into IFO mode

from both arms, W





displacement noise @ 100 Hz, m/rtHz







Figure : BS Elliptical Baffle Scattered Light Displacement Noise

# 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](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=90585) ITM Elliptical Baffle: Clipping Noise. The results show that the lateral motion will cause a negligible DARM noise.

# INTERFACE CONTROL DOCUMENT

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

[D0900428-v5](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=1267)    AdvLIGO Systems, BSC2-L1 Top Level Chamber Assembly
[D0900525-v2](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=1496)    AdvLIGO SUS BSC2-L1, XYZ Local CS for Elliptical Baffle (ITMX,ITMY)
[D0901142-v4](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=2759)    AdvLIGO Systems, BSC2-H1 Top Level Chamber Assembly