LIGO Laboratory / LIGO Scientific Collaboration

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Generic Input Optics Requirements and Standards

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1 Introduction

The intent of this document is to provide a description of the standards and requirements for the Input Optics (IOO) for the Advanced LIGO Detector. The scope of this document is principally on the engineering and implementation requirements and not the performance requirements.

1.1 Purpose

This document describes how the IOO intends to meet the set of generic requirements and standards for the subsystem for Advanced LIGO subsystems.

1.2 Scope

This document does not cover technical design issues nor technical design requirements associated with the Input Optics. Those are covered in the IOO Design Requirements and Conceptual and Preliminary Design Documents.

1.3 Acronyms

The Input Optics Documentation conforms to the standard acronym list put forth in LIGO-E010613-01, "Generic Requirements & Standards for Detector Subsystems". In addition, we define following:

CWP	Calcite Wedge Polarizer
IMC	Input Mode Cleaner
OMC	Output Mode Cleaner
RTP	Rubidium Titanyl Arsenate (electro-optic modulator crystal)

1.4 Applicable Documents

Please see Section 1.5 of LIGO-E010613-01 "Generic Requirements & Standards for Detector Subsystems" for a list of applicable documents.

2 IOO Review Requirements

The required design reviews for the IOO are defined in the Guidelines for Detector Construction Activities as follows:

• Design Requirements Review (DRR)

• Preliminary Design Review (PDR)

• Final Design Review (FDR)

• Pre-shipment Review

The IOO has already completed:

- Design Requirements and Conceptual Design Review (5/6/02)
- Preliminary Design Review I for the Electro-optic Modulators and Faraday Isolators (4/28/06)

and is currently completing PDR II for the layout, mode cleaner, electro-optic modulation architecture, and mode-matching telescope. Documentation for these reviews is available at http://lhocds.ligo-wa.caltech.edu:8000/advligo/Input_Optics_Optics, and in the DCC.

3 Configuration Control

The IO group maintains the Solidworks layout for the vacuum chambers that contain the input optics and will keep this up to date. Configuration control will be maintained via Document Change Notices (DCN), Records of Decision and Agreement (RODA), and by interfaces to other subsystems.

E and D labeled IOO documents which are approved for release will be controlled through the Document Change Notice (DCN) process. Once an IOO document is formally released, all changes will be recorded with new revisions through additional DCNs.

Changes that involve other subsystems will be recorded through the RODA process.

4 IOO Documentation

4.1 Documentation Numbering & Electronic Filing

All IOO documents will be numbered and identified in accordance with the LIGO documentation control numbering system used by the DCC in Adobe Acrobat (*.pdf), and filed in the DCC

All documents will be filed in Adobe Acrobat version 3.0 format.

4.2 Source files

Source files for all IOO engineering documentation (mechanical drawings, electronics schematics, specifications, procedures, etc.) will be archived in the DCC.

A complete list of DCC links of IOO documentation will be maintained at http://lhocds.ligo-wa.caltech.edu:8000/advligo/Input_Optics_Optics.

4.3 Design, Analysis & Test

4.3.1 Design Requirements Document (DRD)

Advanced LIGO Input Optics Design Requirements Document, LIGO T-020020-01-D

Advanced LIGO Input Optics Design Requirements Review, LIGO-G020229-00-D

4.3.2 Conceptual Design Document (CDD)

Advanced LIGO Input Optics Conceptual Design Document, LIGO T-020027-00-D

4.3.3 Preliminary Design Document (PDD)

4.3.3.1 Preliminary Design 1 – Modulators and Isolators

Upgrading the Input Optics for High Power Operation, LIGO-T060267-00-D

Modulators and Isolators for Advanced LIGO, LIGO-G060361-00-D

4.3.3.2 Preliminary Design 2 – IOO PD

Advanced LIGO Input Optics Preliminary Design Document, LIGO T-060269-01-D

4.3.4 Final Design Document (FDD)

Pending.

4.3.5 Technical Design Memorandum

N/A

4.3.6 Test Plans and Procedures

Test plans and procedures are under development for the following IOO subsystems:

- Electro-optic modulators
- Faraday isolators
- Mode cleaner mirror metrology
- Mode-matching telescope mirror metrology

In addition, a Test Plan for the overall IOO system similar to "Input Optics Test Plan" T990028-00-D is under development.

4.3.7 Prototype Test Plans & Results

- Mode cleaner mirror - metrology for triple suspension noise prototype

4.4 Fabrication and Process Specifications

N/A

4.5 Engineering Drawings and Associated Lists

A complete set of drawings used in fabrication of IO components will be provided with the IO Final Design, along with Bill of Material (BOM) and drawing tree lists. The drawings will comply with LIGO standard formats and will be provided in electronic format (Solidworks). Drawings will be assigned DCC numbers in the LIGO drawing numbering system.

4.6 IOO Technical Manuals and Procedures

IOO procedures documentation shall be provided for the following IO components and subsystems at the time of the FDR.

- Electro-optic modulators
- Mach-Zehnder modulation apparatus
- Mode cleaner (installation and alignment)
- Faraday isolator
- IOO baffle assembly

Many of the categories listed below may be combined into a single document for each of the above IOO subsystems. This documentation is currently under development and will be provided at IOO FDR.

4.6.1 Initial assembly and check-out of equipment

4.6.2 Initial installation and setup of equipment

4.6.3 Normal operation of equipment

4.6.4 Normal and/or preventative maintenance

4.6.5 Test of new equipment

4.6.6 Troubleshooting guide for any anticipated potential malfunctions

4.7 Technical Manuals and Procedures

4.7.1 Procedures

Procedure documentation for the major IOO subsystems listed above will be provided at the FDR.

5 IOO Testing Requirements

5.1 Fit Check

All IOO subsystems will be fit checked prior to delivery to the sites.

5.2 Assembly

Assembly and tooling procedures are required for the installation of the IOO in-vacuum equipment:

- MC suspensions
- SOS suspensions
- Faraday isolator
- Mode matching telescope suspensions
- IOO baffles

Procedure documentation will be provided at the FDR.

5.3 Function

'Functional' IOO subsystems include EOMs, MZ electronics, suspended MC mirrors, suspended steering mirrors, suspended MMT mirrors, adaptive MMT ring heater and mode-matching sensor, and the Faraday isolator. All IOO subsystems will be tested for function prior during assembly.

All suspended mirrors will undergo metrology to check reflectivity, transmission, radii of curvature.

All 'off-the-shelf' items (such as opto-mechanical mounts, mirrors, photodiodes, etc.) will be certified by inspection after receipt from the vendor.

5.4 Performance

Performance certification checklists will be developed for:

- Electro-optic modulators
- Mach-Zehnder modulation apparatus
- Mode cleaner (installation and alignment)
- Faraday isolator
- Adaptive MMT

5.5 Self-Test

N/A

5.6 Installation

TBD

6 Mechanical Characteristics & Standards

6.1 Naming Conventions

6.2 Part numbers

All designed and fabricated mechanical parts shall use the naming convention laid out in LIGO-E010613-01-D: “All fabricated LIGO parts shall have a part number designation. The part number is identical to the drawing number, including the revision letter.”

6.3 Serial numbers

IOO parts for which data is to be collected for individual items (inspection data, performance data, characteristics, etc.) will have individual serial numbers.

For large optical components, serial numbers will be engraved along the barrel of the optic as prescribed in the design drawing.

For large fabricated mechanical components, serial numbers will be engraved in a place prescribed in the component drawing.

For small optical and mechanical components, placing serial numbers on the parts is impractical.

For commercial components, serial numbers will correspond to the vendor catalog serial number.

6.4 Coordinate system

The IOO uses the coordinate system definition in accordance with LIGO-T980044.

6.5 Structural Safety Factor

N/A

6.6 Materials

6.7 Processes

6.7.1 Cleaning

All IOO materials used inside the vacuum chambers will be cleaned in accordance with E960022-B, LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures. Final cleaning & vacuum preparation of parts will be performed after all processing has been completed, when possible.

6.8 Welding and Brazing

N/A

6.9 Finishes

All IOO in-vacuum components will be finished to CNC machine precision, except where functionality calls out for a specific finish (eg, a diffusing beam dump). There are very few dissimilar metal surface-to-surface joints in the IOO in vacuum.

IOO components on the PSL, IOT, and ISC tables will be

6.10 Bolted Joints and Threaded Fasteners

Several in-vacuum IOO parts will require assembly with screws. All in-vacuum fasteners shall use oversize tapped threads to prevent galling, in accordance with E030350, Drawing Requirements.

Aluminum: IOO aluminum in-vacuum parts that are expected to be disassembled will use stainless steel screws in Nitronic-60 (N60) thread inserts for the tapped holes,

Stainless Steel: Silver-plated, stainless steel screws shall be used in 0.005” oversize tapped stainless IOO parts.

6.11 Drawing Standards

IOO drawings will follow the standards given in LIGO-E030350, “Drawing Requirements”

6.12 CAD Standards

IOO CAD will follow the standards given in LIGO-E030350, “Drawing Requirements”

6.13 Interchangeability

6.14 Workmanship

6.15 Human Engineering

6.16 Preparation for Delivery

Packaging and marking of IOO equipment for delivery will be done in accordance procedures put forth in LIGO-E010613-01, “Generic Requirements & Standards for Detector Subsystems”

7 Electrical Characteristics & Standards

7.1 Naming Conventions

7.2 Grounding and Shielding

7.3 EMI/EMC

All IOO electrical/electronics equipment shall meet the Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) requirements of the following two documents:

- "LIGO EMI Control Plan and Procedures", E960036-A
- "LIGO Interferometer Electronics EMC Requirements", E020986-01

7.4 Cabling

All IOO cable will follow the standards laid out in LIGO-E960177 "LIGO Cable Numbering and Marking Standards"

7.5 Connectors

7.6 Bus Architecture

7.6.1 EPICS control interface

7.6.2 Workmanship

7.6.3 Software Characteristics & Standards

7.7 TBD

7.8 GUI Human Engineering

8 Vacuum Compatibility Requirements

8.1 Materials

Vacuum qualified materials are listed in LIGO-E960050-B-E, “LIGO Vacuum Compatible Materials List”. The IOO anticipates using some or all the following materials for in vacuum components.

8.1.1 Metals

- Aluminum Alloys
- Indium
- 304 Stainless Steel
- OFHC Copper
- Phosphor bronze
- Nichrome*

* Nichrome is not listed in LIGO-E960050-B-E as qualified or provisional

8.1.2 Crystalline materials

- DKDP (deuterated KDP)*
- TGG (Terbium Gallium Garnet)**

* KPD is qualified; DKDP should have similar outgassing rates
** TGG is not listed in LIGO-E960050-B-E as qualified, but was used in initial LIGO

8.1.3 Glass and amorphous materials

- Fused Quartz
- BK7
- Silicon dioxide (optical coating)
- Tantalum Pentoxide (optical coating)

8.1.4 Sintered Materials

- NdFeB (NEO) magnets*

* NdFeB is listed in LIGO-E960050-B-E as a provisional material; was used in initial LIGO

8.1.5 Active Components

- New-Focus picomotor 8301-UHV*

*qualified for E-LIGO

8.1.6 Plastic Insulators and Polymers

- Kapton wire insulation*
- Vac Seal epoxy*

* listed in LIGO-E960050-B-E as a provisional material; was used in initial LIGO

8.2 Qualification and Cleaning

Vacuum qualification and cleaning procedures are given in LIGO-E960022- B-E, LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures”

9 Acoustic Requirements

There are no significant noise generating components in the IOO subsystem. PZT actuators on the Mach-Zehnder (MZ) modulator, positioning mirrors, may generate acoustic noise at frequencies up to 5 kHz, but at levels *well* below 3 x 10^{-7} Pa/$\sqrt{Hz}$, the limit quoted in LIGO-E010613-01.

10 Earthquake Requirements

IOO components that are subject to potential damage from earthquakes include the suspended in-vacuum optical components, optics that are physically displaced from mounts, and structures on periscopes. It is also possible that a misaligned laser beam would cause damage through direct radiation.

10.1 Severe Earthquake Motion: Maintaining Structural & System Integrity

For severe earthquakes, the IOO would most likely suffer damage from suspended optics that are resonantly excited by ground motion coupled through the HAM ISI and suspensions. The SUS group is responsible for designing safety cages that cradle optics in the event they slip during an earthquake.

All IOO suspended optics use wire suspensions and have bonded magnets, thus likely damage includes the loss of magnet standoffs and wire guide rods. This level of damage is acceptable (E010613-01, section 10).

For damage caused by misaligned laser beams striking unprotected surfaces, spares of all long lead item optical components, crystals, etc. will be available.

10.2 Moderate Earthquake Motion: No Damage Threshold

For the IOO, moderate ground motion may affect the IOO at the level of misalignments. This is considered acceptable.

10.3 Minor Ground Motion: Maintaining Operation

All IOO systems will be able to operate through the 95th percentile limits of ground motion defined in E. Daw's long term study of the LIGO seismic motion.[1] Given the design performance of the HAM ISI and IOO suspensions as well as historical data from LHO and LLO, this should be trivial to satisfy this requirement.

[1] E. Daw, Long Term Study of the Seismic Environment at LIGO, Class. Quantum Grav., 11 Mar 2004, P040015-00

11 Quality Assurance

11.1 Quality conformance inspections

Design and performance requirements for IOO components will be verified by inspection, analysis, demonstration, similarity, test, or a combination of these. See section 5 for testing details

11.1.1 Inspections

Visual inspection of IOO components shall be used to determine conformity with requirements that are neither functional nor qualitative, (eg, identification marks, dimensions, etc.)

11.1.2 Analysis

Analyses will be used for determination of qualitative and quantitative properties and performance of an item by study, calculation, and modeling.

11.1.3 Demonstration

The performance of fasteners, tools, etc will be qualified by demonstration.

11.1.4 Similarity

.Commercial items (mounts, posts, clamps, lenses) will be qualified by similarity. The exception is that focal lengths of commercial lenses will be measured.

11.1.5 Test

The performance of the electro-optic modulators (EOM) will be tested on the bench after assembly using RF generators at the design opterating frequencies and amplitudes and optical spectrum analyzers to determine the modulation depths.

The performance of the Faraday isolators (FI) will be tested on the bench after assembly using low-power lasers and commercial photodetectors to determine the forward transmission and the isolation ratio.

12 Reliability

Estimated IOO component reliability in Advanced LIGO derives from operational up-time and MTBF. IOO components and subsystems will meet SYS requirements for operational up-time (defined as operation at design sensitivity).

12.1 Reliability Requirements for IOO components and subsystems

12.1.1 Optical Components

We require that all optical components meet the SYS requirements for up-time and MTBF.

Optical components can suffer degraded performance (e.g., reduced transmission or reflection) due to surface contamination or surface damage. This can occur gradually over time or suddenly due to optical damage. Degradation of performance is typically associated with surface contamination due to improper handling and cleaning or poor environmental conditions (eg, high levels of dust).

For commercial components, vendor specifications on damage thresholds (when available) will be used to assess reliability. Cleaning and handling procedures based on initial LIGO experience will be developed for all AdvLIGO optical components. Finally, requirements for environmental conditions (satisfactory dust levels) inside the PSL and sensing tables are under development.

Optical damage due to a direct laser beam hit in an inappropriate place (eg, electrode of an RTP crystal) will be minimized by using beam guards where possible and careful alignment procedures.

12.1.2 Electronic Components

TBD

12.1.3 Mechanical Components

Most of the IOO mechanical components are static and not subject to failure.

12.2 Reliability Testing

12.2.1 Optical Components

Reliability tests have been developed for the EOMs and FI to assess their long-term performance and stability under sustained high laser power illumination.

12.2.2 EOM

Testing of the damage threshold and long term stability of RTP at 100 W power levels and at focused intensities ten times in excess of expected AdvLIGO levels have been developed and performed.

No deterioration of performance was seen over 300 hours of sustained operation for 100 W exposure with intensities a factor of two in excess of expected AdvLIGO levels.

No damage was observed after focusing at 10 times the expected AdvLIGO intensity for a few hours.

Based on these measurements, we can put an upper limit of $t = \infty$ on the uptime of the EOMs. Nonetheless, spares will be available if needed.

12.2.3 Faraday Isolator

Reliable performance of the FI can be affected by optical damage (see section 12.1.1 above) or by degraded isolation in vacuum.

12.2.3.1 Optical Damage

During the process of certifying the E-LIGO Faraday isolators, we have recently discovered that the AR coatings on the TGG crystals can suffer microscopic damage at 30 W laser powers. In order to understand this better, we are analyzing the environmental conditions (dust levels) and quality of AR coatings to determine a course of action (better contamination control vs vendor qualification of coatings).

12.2.3.2 Degraded isolation

12.2.4 MC mirrors

Due to the high intracavity powers, damage to MC mirror coatings can occur from sustained exposure over long periods. Quoted damage thresholds for mirror coatings are typically based on short time exposures, and not much is known about long term effects UF has set up an in-vacuum damage testing facility to investigate mirror damage thresholds. Damage testing will begin in the Fall 2007.

13 Maintainability

Generic requirements for maintainability have not yet been developed. When they are, we'll address them.

14 Transportability

All IOO components and subsystems require transport to the sites from either UF or place of manufacture. In addition, several IOO components require multiple processing steps and/or metrology at different vendors before delivery to the sites. Packaging and shipping procedures should insure that no damage will occur to IOO components shipments.

LIGO process travelers will accompany all shipped parts.

14.1 Custom IOO Optics

Custom IOO mirrors (MC mirrors, MMT mirrors, steering mirrors) will be shipped multiple times during processing and metrology. The IOO group is designing special optics containers (similar to the COC shipping containers) which will be used to ship mirror substrates to polishing and coating vendors and to the sites.

All optics packaging will be marked as FRAGILE in prominent lettering, with appropriate THIS SIDE UP markings and tip/tilt and shock sensors placed on the packaging.

14.2 Custom IOO Manufactured Components

14.2.1 Metal parts and assemblies

Large and heavy metal parts and assemblies will wrapped in protective bags and protected by foam-in-place packaging and industry standard wooden crates

Smaller parts will be wrapped in protective bags and cardboard boxed using bubblewrap or Styrofoam peanut protection. Double-boxing will be used (small boxes for parts put in large boxes for shipping).

14.2.2 Faraday isolator magnets

The FI magnets require special shipping and handling owing to their strong magnetic fields (~1 T) and delicate nature (sintered material).

Special shipping containers have been designed for the Faraday rotator magnet rings and for the full rotator assembly. They will be marked with caution labels: FRAGILE and HIGH MAGNETIC FIELDS.

14.3 Commercial IOO Components

Commercial IOO components received from vendors will be inspected and repackaged in the original containers when possible for shipment to the sites.

15 Safety

15.1 FEMA

A Failure Effects and Modes Analysis (FEMA) will be developed for the IOO subsystem. For subsystems, comprised of multiple, non-interacting systems or assemblies, separate FEMAs on each system or assembly may be more suitable.

- EOM/MZ
- MC
- MMT
- FI
- IOO Diagnostics

15.2 Personnel Safety

Laser safety is addressed in the project-wide laser safety plan for Advanced LIGO and the site-wide Laser Safety Plans. See section 15.3.

The Faraday rotator contains a powerful permanent magnet. Consequently, there is risk of minor injury to personnel if tools are suddenly "grabbed" by the magnetic field, which surrounds the rotator housing out to a distance of approximately 30 cm. To mitigate this, IO will procure nonmagnetic tools, made from stainless steel, for the Faraday assembly onto its breadboard and the Faraday alignment. This activity takes place in the optics laboratory. The tools will be vacuum compatible (Class B) and can be used for mounting the breadboard in the HAM vacuum chambers if deemed necessary.

There are numerous heavy components used in the IO subsystem, including the triple suspensions used in the mode cleaner, the large optic suspension used for MMT3, and the Faraday breadboard. IO will work with SUS to develop tooling and procedures for installation of these items into the HAM chambers without injury to personnel or other components in the chambers.

15.3 Laser Safety

A SYS wide laser safety plan for Advanced LIGO is under development. In addition, LLO and LHO have site wide laser safety plans.

- LIGO Livingston Observatory Laser Safety Plan, M040112-07
- LIGO Hanford Observatory Laser Safety Plan, M020131-01

The University of Florida also has developed a Laser Safety Plan for the LLO High Power Test Facility:

- Laser Safety Plan, UF High Power Laser Facility at the LLO, LIGO-M030100-00-L

15.4 Machine Safety