LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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AOS: Optical Lever System & Viewports Conceptual Design Requirements

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Abstract

The AOS system is comprised of the following distinct subsystems: Stray Light Control (SLC), Thermal Compensation System (TCS), PO Mirror Assembly and PO Telescope, Initial Alignment System (IAS), Optical Lever System (OptLev), Photon Calibrator, Output Mode Matching Telescope (OMMT), and Viewports.

This document will present the design requirements and conceptual designs for the Optical Lever System and Viewports.

The Optical Lever subsystem provides external means for monitoring the angular positions of all suspended optics with the purpose of aiding in the initial alignment and in preserving a long-term reference for the angular alignment of the suspended optics. The components of this subsystem will comprise external support means for mounting optical transmitters and receivers, laser transmitters and optical receivers, and in-vacuum steering mirrors as required. The interface to the CDS will be analog voltage signals provided by OptLev that are proportional to the pitch and yaw angles of the optics, and to the power level of the received optical lever beam.

The Viewports subsystem provides optical viewports for the passage of all optical beams in and out of the vacuum region(s) of the IFO. The optical beams include the following: optical lever beams, CO2 laser beams for thermal compensation, chamber illumination beams, video camera beams, and optical beams used for interferometer sensing and control (ISC). All viewports are attached to nozzles in the walls of the vacuum system. The Viewports subsystem includes the Video Cameras and the Chamber Illuminators.

1 Introduction

1.1 Purpose

The purpose of this document is to derive the design requirements for the Auxiliary Optics Support (AOS) and to present a conceptual design that meets those requirements. Primary requirements are derived ("flowed-down") from the LIGO principal science requirements. Secondary requirements, which govern Detector performance through interactions between AOS and other Detector subsystems, have been allocated by Detector Systems Engineering.

1.2 Scope

The AOS system is comprised of the following distinct subsystems: Stray Light Control (SLC), Thermal Compensation System (TCS), PO Mirror Assembly and PO Telescope, Initial Alignment System (IAS), Optical Lever System (OptLev), Photon Calibrator, Output Mode Matching Telescope (OMMT), and Viewports.

This document will present the design requirements and conceptual designs for the Optical Lever System and Viewports subsystems.

The Viewports subsystem includes the Video Cameras and the Chamber Illuminators.

1.2.1 Optical Lever System (OptLev)

The Optical Lever subsystem provides external means for monitoring the angular positions of all suspended optics with the purpose of aiding in the initial alignment and in preserving a long-term reference for the angular alignment of the suspended optics. The components of this subsystem will comprise external support means for mounting optical transmitters and receivers, laser transmitters and optical receivers, and in-vacuum steering mirrors as required. The interface to the CDS will be analog voltage signals provided by OptLev that are proportional to the pitch and yaw angles of the optics, and to the power level of the received optical lever beam.

The optical levers are not intended as feedback devices for the Alignment Sensing and Control subsystem.

The optical lever system will use components from Initial LIGO wherever possible.

1.2.2 Viewports

The Viewports subsystem provides optical viewports for the passage of all optical beams in and out of the vacuum region(s) of the IFO. The optical beams include the following: optical lever beams, CO_2 laser beams for thermal compensation, chamber illumination beams, video camera beams, and optical beams used for interferometer sensing and control (ISC). All viewports are attached to nozzles in the walls of the vacuum system.

The suspended optics in the vacuum chambers will be illuminated with a visible flood lamp and viewed by a video camera with sensitivity both in the visible spectrum and @ 1064 nm.

1.3 Definitions

1.4 Acronyms

LIGO - Laser Interferometer Gravity Wave Observatory

AOS - Auxiliary Optics Support

COS - Core Optics Support

IO - Input Optics

SRD - Science Requirements Document

PRM – Power Recycling Mirror

SRM – Signal Recycling Mirror

BS - Beam Splitter

ITMx, ITMy - Input Test Mass in the interferometer ‘X’ or ‘Y’ arm

ETMx, ETMy - End Test Mass in the interferometer ‘X’ or ‘Y’ arm

FM – Fold mirror for folded IFO

AR - Antireflection mirror coating

HR – Hi-reflectance mirror coating

PO - Pick-off Beam

vh - Vacuum housing

SEI - Seismic Isolation subsystem

SUS - Suspension subsystem

ppm - parts per million

ISC- Interferometer Sensing and Control

LSC - Length Sensing and Control

COC - Core Optics Components

ASC - Alignment Sensing and Control

IFO - LIGO interferometer

HAM - Horizontal Access Module

BSC - Beam Splitter Chamber

TBD - To Be Determined

APS - anti-symmetric port signal

LVEA-vacuum equipment area

rms - root-mean-square

p-v, peak to valley

p-p, peak to peak

OPTLEV- optical lever

QPD – quadrant photo diode

EFL – effective focal length

1.5 Applicable Documents

1.5.1 LIGO Documents

1. T952007-04 ASC Design Requirements Document
2. T980019-00 ASC Initial Alignment Subsystem Final Design
3. T960074-07 Suspension Preliminary Design
4. G970130 LOS Final Design Review
5. LIGO-E960036-A LIGO EMI Control Plan and Procedures
6. D970190-B Optical Lever Assembly MMT3
7. D970156-B Position Detector Assy Optical Lever
8. D970102-B 10X Light Source Assy Optical Lever
9. E950111-A LIGO Naming Convention
10. M950046-F LIGO Project System Safety Management Plan
11. T990026-00 Calibration of Optical Levers
12. L060068-00 ASC Vacuum Viewports
13. E960022-B LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
14. E990086-B Component Specification: COS viewport Window
15. D970211-B Video Imaging Assembly ASC Alignment
16. D970212-B Illuminator Assembly ASC Alignment

1.5.2 Non-LIGO Documents

2 General description

The optical lever is intended primarily as a “flywheel” reference for each suspended optic alignment to maintain continuity between installation and operation. It consists of a laser transmitter for producing an optical lever beam that reflects from the suspended optic, and a quadrant photodiode receiver QPD) for detecting the deflection of the beam caused by the angular motion of the suspended optic. The transmitter and receiver are mounted on support structures outside the vacuum, and the incident optical lever beam and the reflected optical lever beam pass in and out of the vacuum chambers through optical lever viewports.

Viewports provide access into the vacuum chambers for other optical beams, e.g. TCS heating beams from a CO2 laser pattern generator, chamber illumination light from an illuminator flood lamp. Video cameras look through viewports at optics within the vacuum chambers to determine the positions of the interferometer beam on the surfaces of the optics.

2.1 Specification Tree

This document is part of an overall LIGO detector requirement specification tree.

2.2 Product Perspective

2.2.1 Optical Lever System Perspective

The optical lever transmitters and receivers are positioned outside the LIGO vacuum chambers. The transmitted optical lever beam passes into the chamber through a viewport in the chamber wall, reflects from the suspended optic; and then, passes out through a viewport onto the optical lever receiver. In-vacuum steering mirrors may be needed to provide access to suspended optics that are either obscured by other components, or are not within the line of sight of available viewports. The amount of light reflected from the suspended optic depends upon the angle of incidence and the reflectivity of the surface of the optic. Many of the optical lever transmitters and receivers from Initial LIGO may be re-used.

2.2.2 Viewports Perspective

Viewports are mounted to flanges in the nozzles of the vacuum chambers. The viewport material and the AR coatings on the viewport surfaces are chosen to maximize the transmissivity of the light passing through the viewport. Many of the previous viewports from Initial LIGO may be re-used.

2.3 Product Functions

2.3.1 Optical Lever System Functions

The Optical Lever system provides three primary functions: 1) provide an angular alignment reference during the initial alignment procedure; 2) provide an independent means for monitoring the long-term global angular orientation of the aligned suspended optic; and 3)provide a global reference for the angular alignment of the suspended optic to aid in maintenance and setup functions such as diagonalization of the core optic, core optic replacement, and realignment caused by catastrophic events (e.g. Earthquakes)

2.3.2 Viewports Functions

Viewports provide access for optical beams to pass into and out of the vacuum chambers, e.g. video camera beams, TCS heating beams from a CO2 laser pattern generator, and chamber illumination light from an illuminator flood lamp.

2.3.3 Viewport Naming Convention

For the purposes of this document, the viewports will be named as follows.

The BSC viewport names are shown in Figure 1. The IFO x-arm is on the right, and the y-arm is up in this figure.

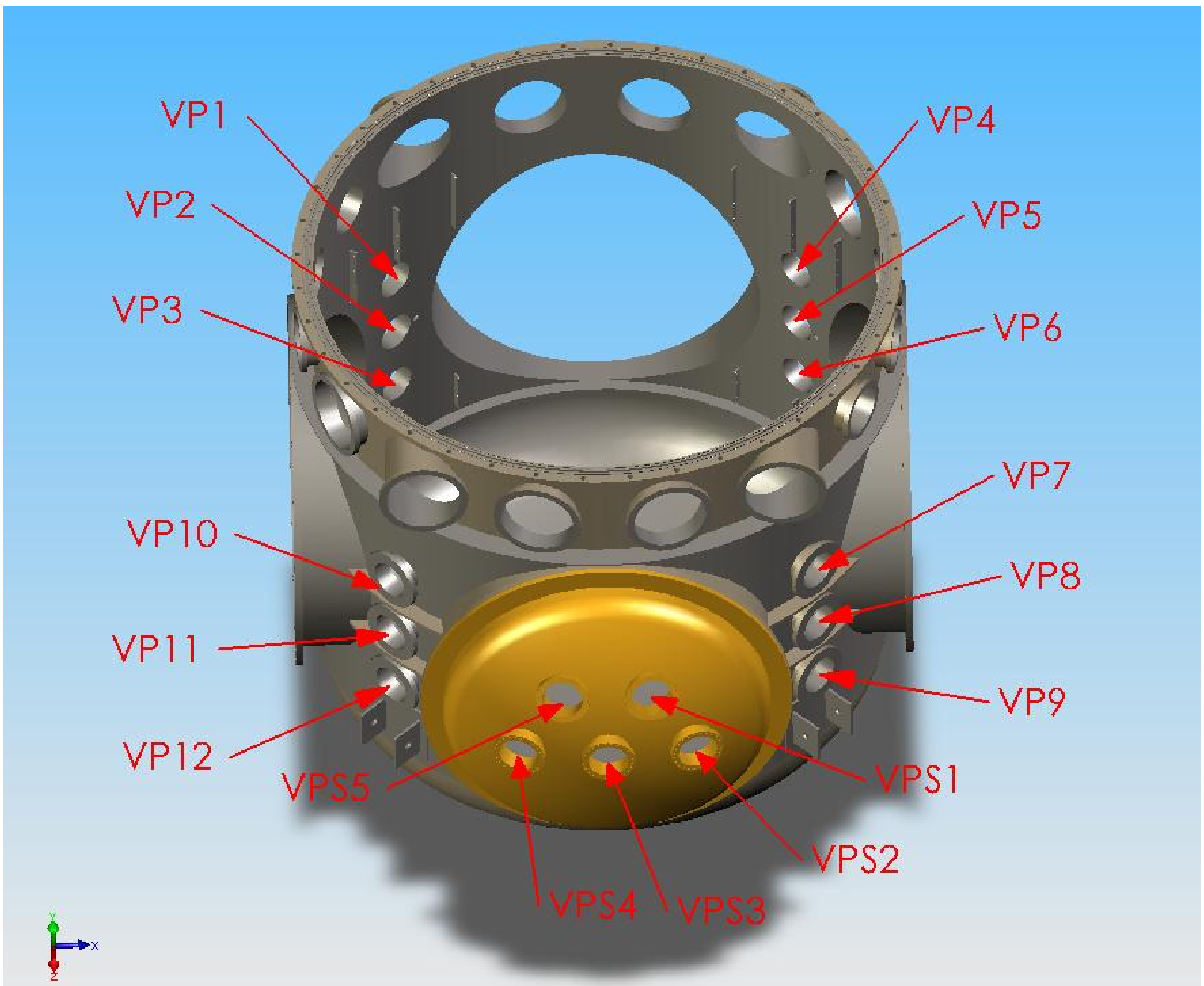

Figure 1: BSC viewport names

The HAM viewport names are shown in Figure 2. The flange on the right of the figure faces toward the vertex of the IFO.

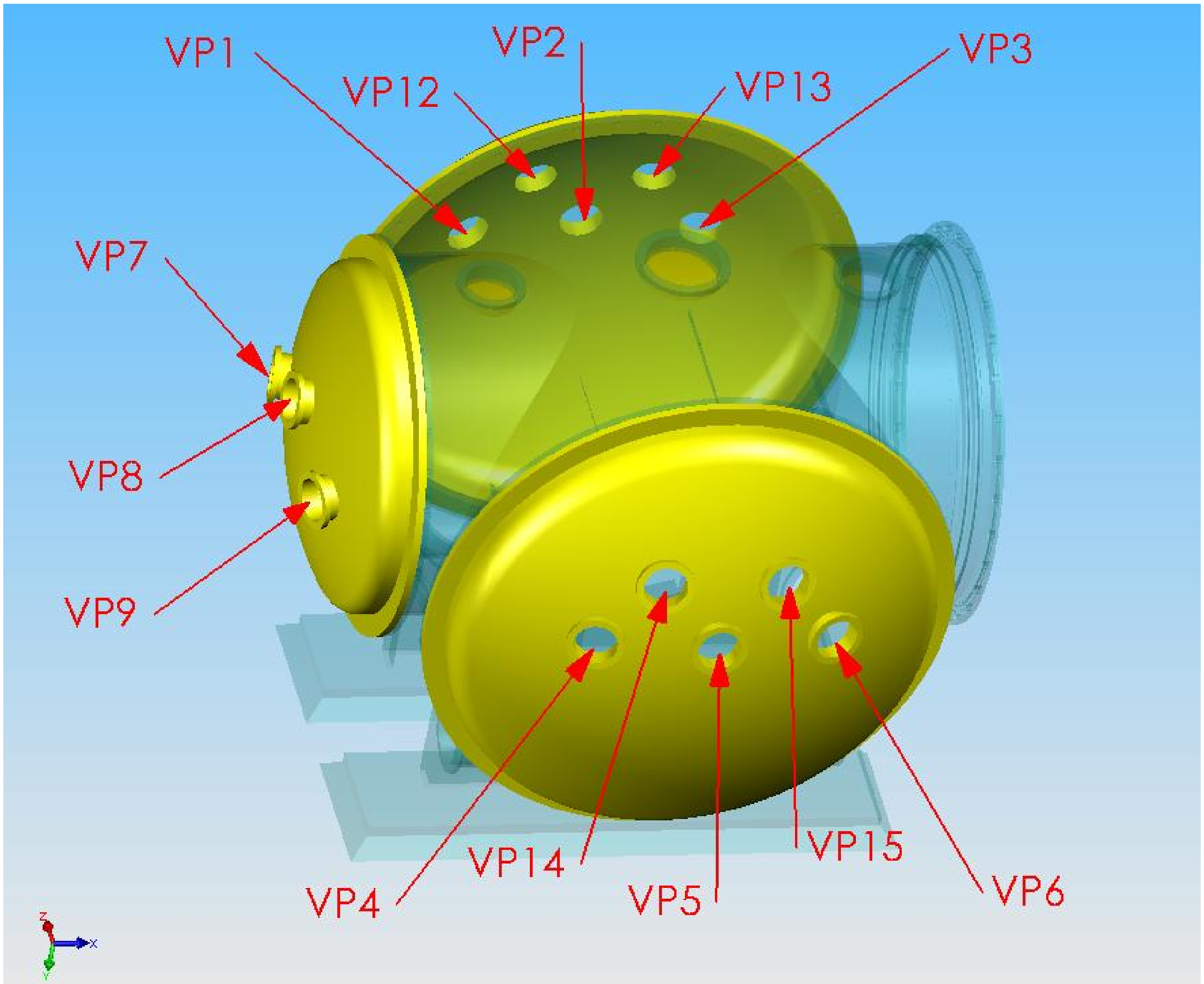

Figure 2: HAM viewport names

The IO and OUT viewports are mounted on the flanges in the nozzles of the IO and OUT manifolds (see Figure 13). The IO and OUT manifold viewport names are shown in Figure 3, where the view is looking toward the manifold. A "-X" designation is added when referring to the side of the IO manifold in the –x direction. A "+X" designation is added when referring to the side of the IO manifold in the +x direction. A "-Y" designation is added when referring to the side of the OUT manifold in the –y direction. A "+Y" designation is added when referring to the side of the OUT manifold in the +y direction.

The A1 and A7 adapter flange viewport names are shown in Figure 4, with the view looking toward the flange.

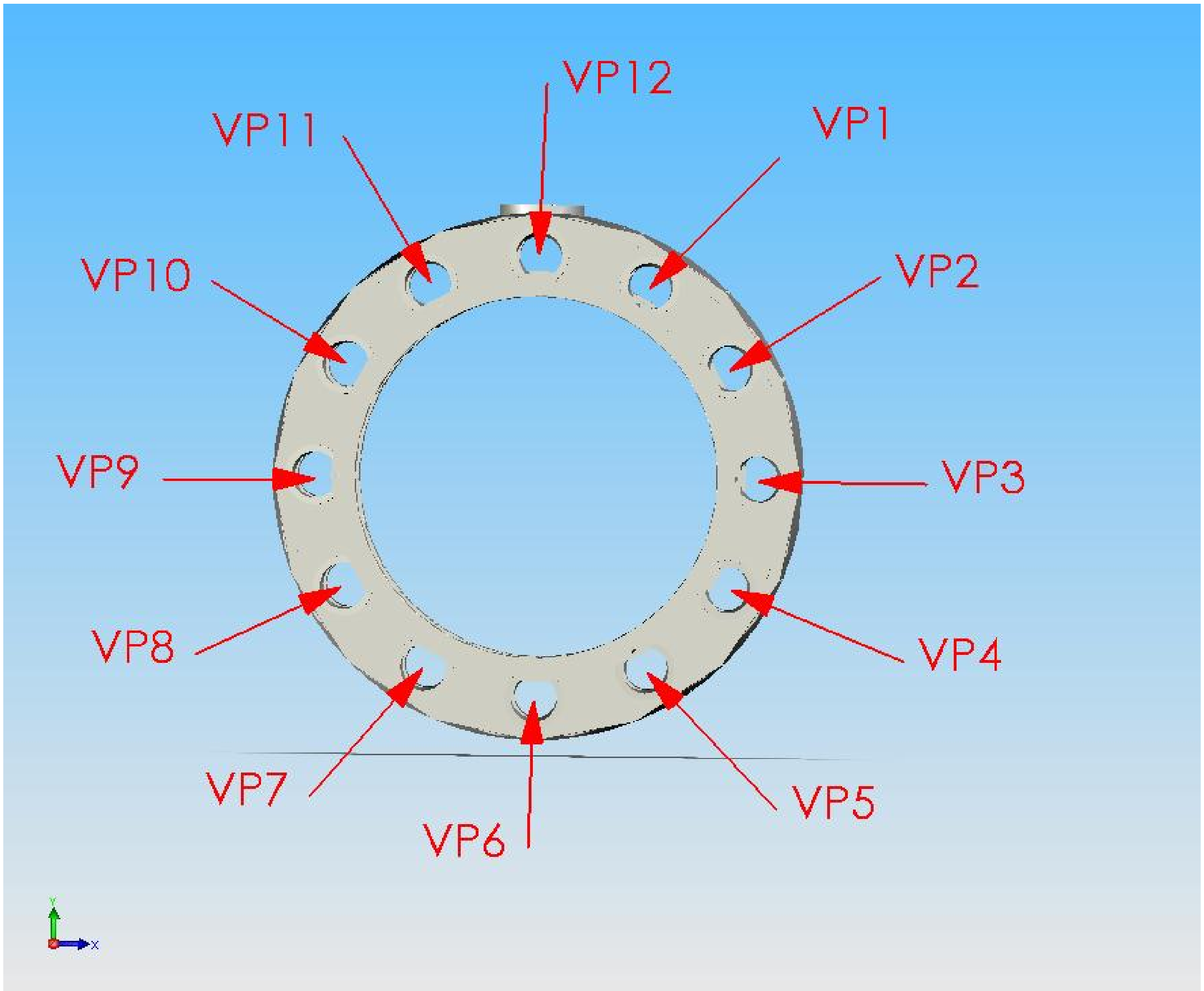

Figure 3: IO and OUT manifold viewport names

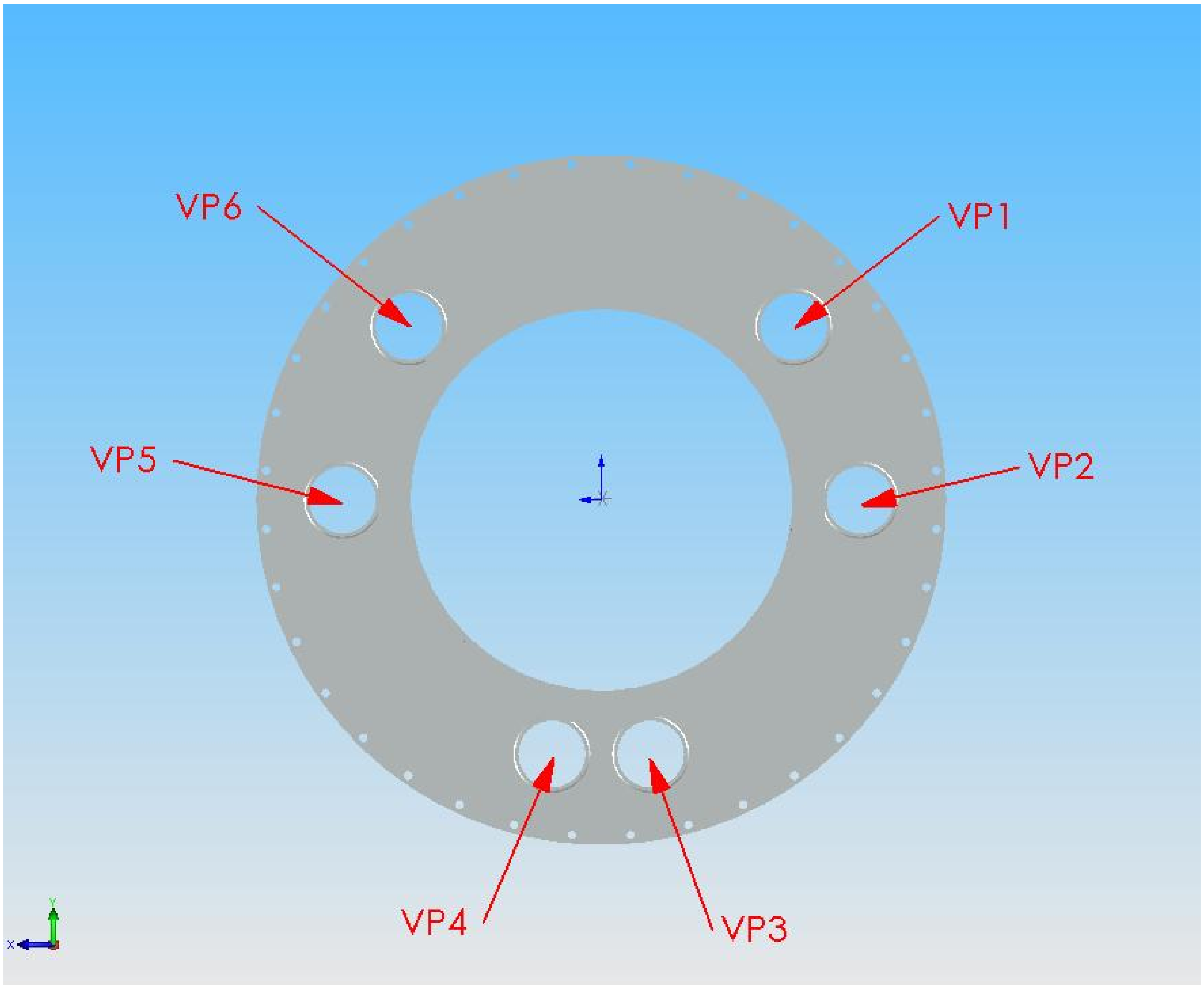

Figure 4: A1 and A7 adapter flange viewport names

2.4 General Constraints

2.4.1 Optical Lever System Constraints

The angular sensitivity of the optical lever may be limited by the optical power received by the optical lever receiver, which is in turn determined by the reflectivity of the suspended optic.

The line of sight of the optical lever beam may be occluded by components on the optical table in front of the suspended optic. This will require additional steering mirrors to direct the optical lever beam to and from the optic. The global reference of those optical lever beams that require steering mirrors inside the vacuum chamber may be compromised due to the motion of the vacuum chambers during pump-down.

2.4.2 Viewport Constraints

The sizes and quantities of viewports are determined by the existing nozzles on the vacuum chambers of Initial LIGO. An exception is the proposed addition of new manifold sections between HAM2 and HAM3, and between HAM5 and HAM6, which will each contain 12 pairs of additional viewports.

2.5 Assumptions and Dependencies

2.5.1 Suspended Optics Parameters

The following mirror reflectivity and mirror diameters for the suspended optics are assumed.

2.5.1.1 Reflectivity

R > 5% @ 635 nm wavelength

2.5.1.2 Mirror Diameter

Small optics (SM1, SM2, MMT1, MMT2)	75 mm diameter
Mode cleaner optics	150 mm diameter
Input optics/recycling cavity (MMT3, PRM, SRM)	285 mm diameter
BS	370 mm diameter
Core optics (ITM, ETM)	340 mm diameter
PO mirror	285 mm diameter

2.5.2 Viewport Flanges

The viewports will mount to standard 10 in outside diameter (OD) and 4.5 in OD conflat flanges attached to the vacuum chambers.

2.5.3 Optical Lever Angular Resolution

A 100 micro radian angular resolution will be sufficient for the initial alignment of the suspended IFO mirrors.

2.5.4 CDS Interface Characteristics

A suitable analog signal cable will be provided by CDS for access to the QPD signals. CDS will convert the raw QPD voltages into pitch and yaw signals.

CDS will provide appropriate electrical power for the optlev diode lasers, the QPD circuit, and the illuminators.

2.5.5 Seismic Environment

It is assumed that no catastrophic seismic events will occur, other than the normal benign seismic disturbances that cause loss of lock in the IFO.

3 Requirements

3.1 Optical Lever System Requirements

3.1.1 Introduction

The optical lever system shall measure the angular orientation of all suspended optics during and after their installation. The optical lever system shall be used for damping the suspended optics during the initial lock acquisition phase. The optical levers shall provide analog voltages that can be converted into global pitch and yaw angles of each suspended optic with respect to the local facility foundation.

3.1.1.1 Angular Resolution

The angular resolution requirements for the optical lever system will be the same as the requirements for the initial alignment mode of Initial LIGO, as stated in T952007-04 ASC Design Requirements Document, 3.2.1.1; T980019-00 ASC Initial Alignment Subsystem Final Design, 4.2; and summarized in the following.

For installation of suspended optics, the optical lever system will measure the angular deviation of the suspended optic from the aligned beam axis to within 10% of the SUS actuator angular dynamic range. We will apportion the angular error of the optical lever equally between the angular resolution and the pointing instability of the transmitted optical lever beam. The angular dynamic ranges for the Initial LIGO LOS and SOS suspended optics are > 2 mrad p-p in pitch and yaw (G970130 LOS Final Design Review); therefore, the optical lever positioning accuracy requirement is 0.1 mrad p-p.

The optical lever angular resolution shall be < 0.05 mrad.

3.1.1.2 Pointing Stability

The long-term, angular pointing stability of the optical lever system shall be < 0.05 mrad.

3.1.1.3 Relative Intensity Noise

TBD

3.1.1.4 Mean Time Before Failure

The mean time before failure (MTBF) has not been established as a Science Requirement, although in principal it could flow down from the requirement to maintain a 90% duty factor for each individual IFO. There is documented experience from Initial LIGO that indicates the MTBF for the optical lever laser is > TBD. This lifetime experience will be taken as a goal.

The MTBF for an individual optical lever will be > TBD.

3.1.1.5 Tilt to Lateral Displacement Cross-coupling

When the optical lever beam reflects from an optical surface at a large incidence angle, the reflected beam is displaced laterally in the plane of incidence as the optic is tilted. For the case of the PRM in Initial LIGO and for some of the optics in the IO section of ADLIGO, the lateral displacement at the Oplev receiver may be as high as 13% of the angular displacement. This cross-coupling may result in ambiguity of the optical lever signal and may compromise the use of the optical lever for damping of the suspended optic during initial lock acquisition.

The tilt to lateral displacement cross-coupling has not been established as a Science Requirement. However, we will set a reasonable goal.

The tilt to lateral displacement will be <1%.

3.1.1.6 Optical Lever Maintainability

The pointing requirement of the optical lever shall not be compromised whenever an optical lever laser or a QPD is replaced, or whenever the optical lever support structure is moved temporarily to allow access to a vacuum chamber.

3.1.1.7 EMI

Electromagnetic Radiation from the diode laser shall meet the EMI and EMC requirements of VDE 0871 Class A or equivalent. The subsystem will also comply with LIGO-E960036-A LIGO EMI Control Plan and Procedures.

3.2 Viewport Requirements

3.2.1 Video Camera Viewport

3.2.1.1 Optical Distortion

The video camera viewport shall have minimum optical distortion so as to enable the video camera resolution to be > 250 TV lines resolution in the horizontal and vertical directions.

3.2.1.2 Optical Transmissivity

The optical transmissivity of the video camera viewport shall be > 99% at the wavelengths 635 nm and 1064 nm, normal incidence.

3.2.1.3 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.2 Chamber Illumination Viewport

3.2.2.1 Optical Transmissivity

The illumination viewport shall transmit a sufficient quantity of visible light to enable the video camera resolution of mirror features to be > 250 TV lines resolution in the horizontal and vertical directions.

3.2.2.2 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.3 Optical Lever Viewport

3.2.3.1 Optical Transmissivity

The optical transmissivity of the optical lever viewport shall be > 99% at the wavelengths 635 nm and 1064 nm, normal incidence.

3.2.3.2 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.4 Brewster's Angle Viewport

3.2.4.1 Surface Quality

The Brewster's angle viewport shall have a surface micro-roughness < 0.8 Angstroms.

3.2.4.2 Wavefront Distortion

The wavefront distortion across a 4.5 inch clear aperture shall be < 1/10 wave @ 633 nm wavelength.

3.2.4.3 Optical Transmissivity

The transmissivity shall be > 99% @ 1064 nm wavelength, at 56 deg incidence.

3.2.4.4 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.5 TCS Viewport

3.2.5.1 Surface Quality

The TCS Viewport shall have a surface quality of at least scratch/dig 20-10.

3.2.5.2 Wavefront Distortion

The wavefront distortion across a 2.5 inch clear aperture shall be < 1 wave @ 633 nm wavelength.

3.2.5.3 Optical Transmissivity

The transmissivity shall be > 99% @ 10.6 micron wavelength, and >90% @ 635 nm wavelength, normal incidence

3.2.5.4 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.6 Hartmann Viewport

The viewports for the Hartmann beams will be the same as were used for the PO beams in Initial LIGO (see E990086-B Component Specification: COS viewport Window)--2.75 in clear aperture, optical grade A fused silica.

3.2.6.1 Surface Quality

The viewports shall have a surface quality of at least scratch/dig 10-5.

3.2.6.2 Wavefront Distortion

The wavefront distortion across the 2.75 inch clear aperture shall be < 1/10 wave @ 633 nm wavelength.

3.2.6.3 Optical Transmissivity

The viewport shall be AR coated at the Hartmann beam wavelength (TBD) for >99% transmissivity.

3.2.6.4 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.2.7 PSL Viewport

The viewport for the PSL beam will be the same as was used for the PO beams in Initial LIGO (see E990086-B Component Specification: COS viewport Window)--2.75 in clear aperture, optical grade A fused silica.

3.2.7.1 Surface Quality

The viewport shall have a surface micro-roughness < 0.8 Angstroms.

3.2.7.2 Wavefront Distortion

The wavefront distortion across the 2.75 inch clear aperture shall be < 1/10 wave @ 633 nm wavelength.

3.2.7.3 Optical Transmissivity

The transmissivity shall be > 99.9% @ 1064 nm wavelength, at 5.3 deg incidence, with S-polarization.

3.2.7.4 Pressure Differential

The viewport shall safely withstand a 1 ATM pressure differential across both faces.

3.3 Video Camera Requirements

3.3.1 Resolution

The video camera shall provide adequate spectral sensitivity @ 635 nm and @ 1064 nm to enable a resolution > 250 TV lines horizontal and vertical.

The minimum light level to achieve 250 TV lines resolution shall be < 400 lux, f/8.

3.3.2 Video Format

The system video signal shall be EIA standard.

3.3.3 EMI

Electromagnetic Radiation from the video camera shall meet the EMI and EMC requirements of VDE 0871 Class A or equivalent. The subsystem will also comply with LIGO-E960036-A LIGO EMI Control Plan and Procedures.

3.3.4 MTBF

The MTBF of the video camera shall be > 70000 hrs.

3.4 Chamber Illumination Requirements

3.4.1 Illumination Level

The chamber illumination shall provide sufficient visible light to enable the video camera resolution of mirror features to be > 250 TV lines resolution in the horizontal and vertical directions.

3.4.2 EMI

Electromagnetic Radiation from the illuminator shall meet the EMI and EMC requirements of VDE 0871 Class A or equivalent. The subsystem will also comply with LIGO-E960036-A LIGO EMI Control Plan and Procedures.

3.4.3 MTBF

The MTBF for the illumination lamp shall be >3000 hrs.

4 Conceptual Design

4.1 Optical Lever System

Two types of optical lever receivers will be used for Advanced LIGO: 1) OPTLEV 4 receiver lens, and 2) Initial LIGO lens-less QPD receiver. The lens-less QPD receiver will be used whenever the lever arm is > 13 m and the incidence angle is less than 10 degrees. This will provide the same or better angular resolution as in Initial LIGO with a smaller tilt-displacement cross-coupling error.

The optical lever types for each suspended optic in the non-folded IFO are summarized in Table 1.

Table 1: Summary of SUS optical lever type, non-folded IFO

IFO	SUS	INCIDENCE ANGLE, deg	LEVER ARM, m	TYPE OF OPTLEV
Non-folded				
	MC1	42.3	1.1	OPLEV4
	MC2	5.7	15.0	QPD
	MC3	20.2	15.0	OPLEV4
	SM1	9.2	4.9	OPLEV4
	SM2	37.2	4.3	OPLEV4
	MMT1	0.0	3.0	OPLEV4
	MMT2	5.5	15.0	QPD
	MMT3	4.1	15.0	QPD
	PRM	3.7	15.0	QPD
	BS	6.2	1.9	OPLEV4
	ITMX	1.3	35.0	QPD
	ITMY	1.3	35.0	QPD
	ETMX	6.9	6.0	OPLEV4
	ETMY	7.3	6.0	OPLEV4
	SRM	3.6	15.0	QPD
	OMMT1	4.0	15.0	QPD
	OMMT2	3.4	15.0	QPD
	OMMT3	54.2	1.7	OPLEV4
	BS PO M1	61.3	1.2	OPLEV4
	BS PO M2	14.4	1.5	OPLEV4

4.1.1 Optical Lever System Characteristics

4.1.1.1 Optical Lever System Performance Characteristics

4.1.1.1.1 Long Focal Length Receiver Lens

A telecentric, 13.6 meter EFL prototype optical lever receiver, described as OPTLEV 4, was designed, built, and tested. A schematic layout of the prototype OPTLEV 4 receiver is shown in Figure 5. The reflected optical lever beam from the suspended optic enters the receiver from the left through the objective lens and is focused with an optical train onto the surface of a quadrant photo diode (QPD) at the right side of the drawing.

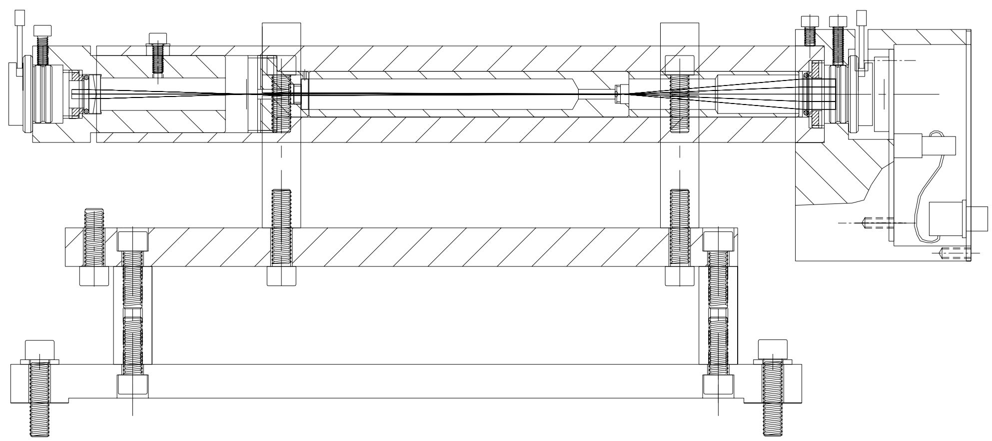

Figure 5: 13.6 EFL Optical Lever Receiver

The optical receiver design was analyzed using a Gaussian beam propagation mathematical model and a ZEMAX optical design program.

The Zemax optical layout for the 13.6 m OPTLEV 4 is shown in Figure 6. It includes a Beam expanding telescope for the laser transmitter and a wedge to simulate the tilt of the suspended optic. The distances between the transmitter and wedge, and between the wedge and the optical lever receiver can be adjusted to simulate the actual distances in the IFO. The simulated spot size and shape on the QPD was determined with the physical optics propagation program of ZEMAX. A typical spot cross-section at the QPD is shown in Figure 7.

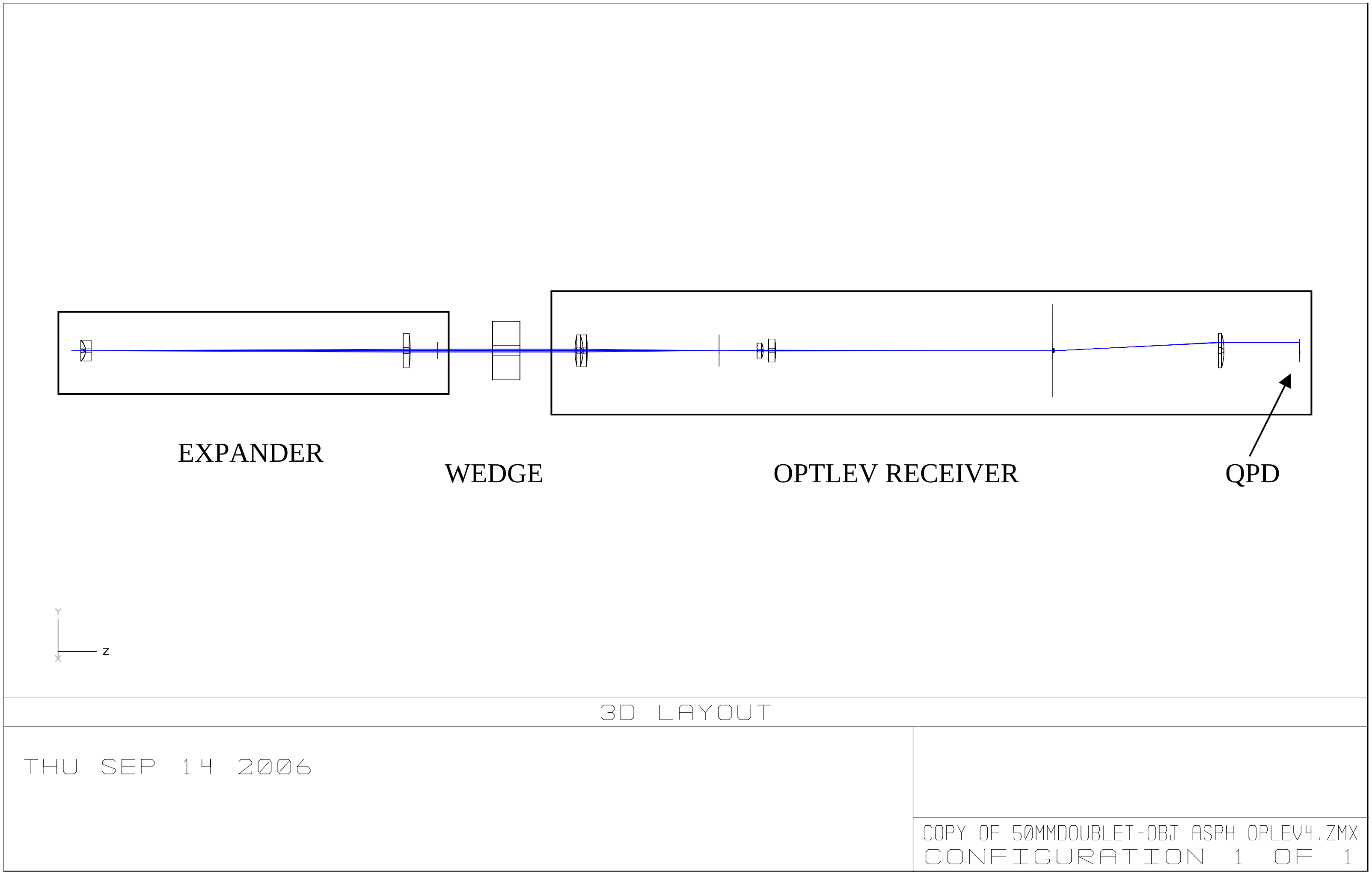

Figure 6: Optlev Receiver, ZEMAX model

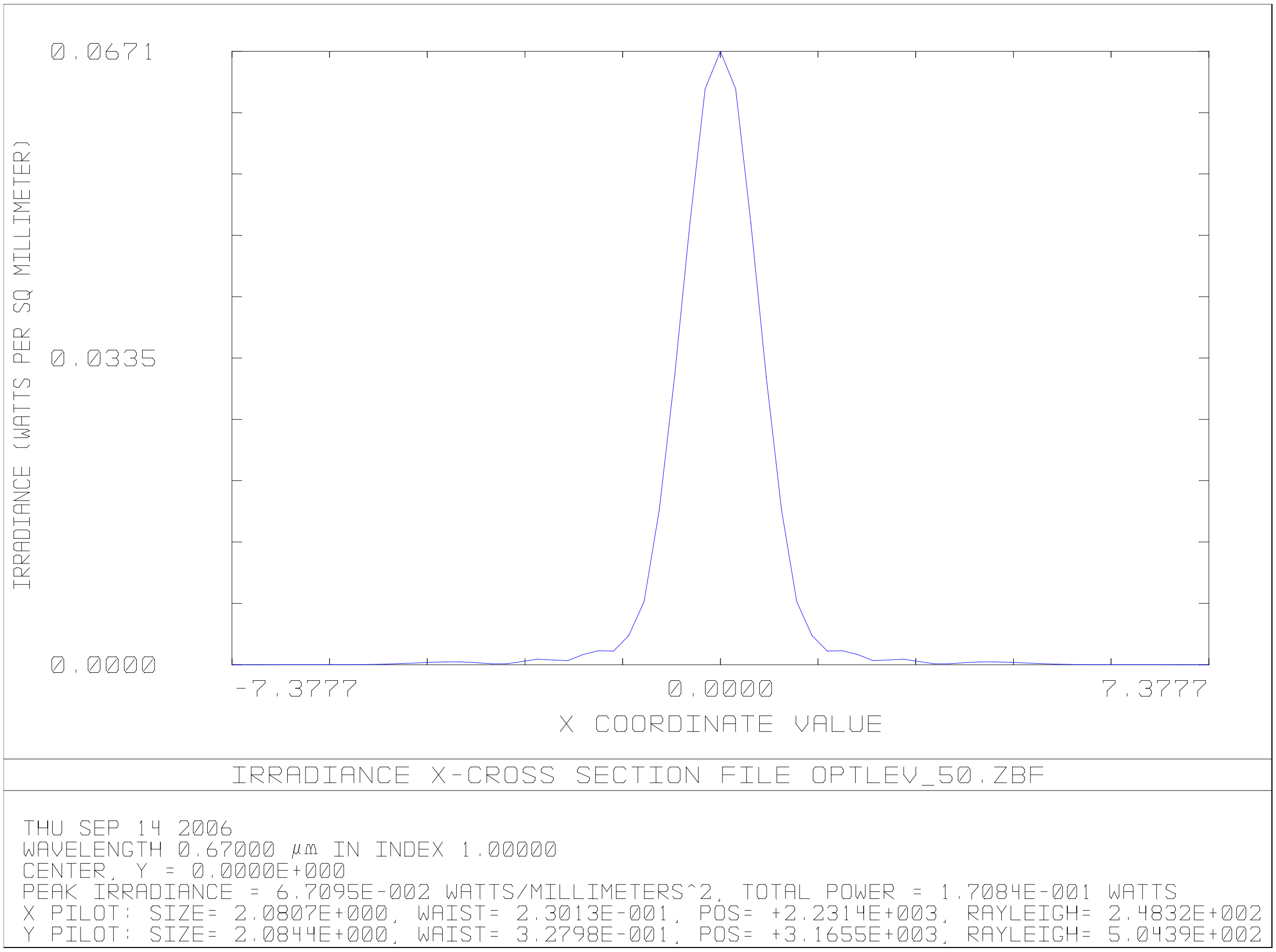

Figure 7: Spot cross-section at QPD, 13.6 EFL OPLEV 4

4.1.1.1.2 Angular Resolution

The height of the focused spot at the plane of the QPD versus input angle for the 13.6 EFL receiver, as calculated by a paraxial Gaussian beam propagation model is shown in Figure 8.

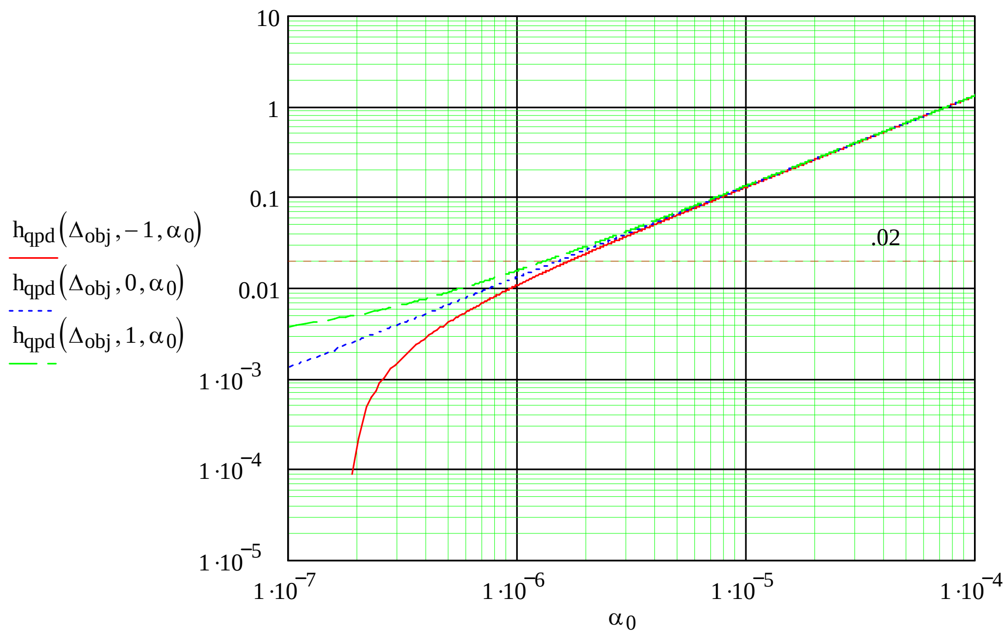

Figure 8: Spot height at QPD vs. input angle, 13.6 EFL

The minimum height that can be resolved on the QPD is assumed to be 20 microns, as indicated by the horizontal line in the graph—the minimum detectable height may be as small as 5 microns depending upon the amount of laser power incident on the QPD. The blue dotted line is the output height for an on-axis beam, and the red solid line and green dashed line are the output heights when the input beam is displaced laterally on either side of the on-axis beam by 1 mm.

If 20 microns is taken as the minimum resolvable height, then the 13.6 EFL optlev receiver design has a linear response and an angular resolution of < 2 micro radian, which exceeds the requirement 3.1.1.1.

4.1.1.1.3 Pointing Stability

TBD- The pointing stability of the Initial LIGO optical lever laser was measured at LHO. Get data from Doug Cook.

This meets the requirement 3.1.1.2

4.1.1.1.4 Relative Intensity noise

TBD- The relative intensity noise of the Initial LIGO optical lever laser was measured at LHO. Get data from Doug Cook.

This meets the requirement 3.1.1.3.

4.1.1.1.5 Tilt to Lateral Displacement Cross-coupling

A lateral translation of the optical lever beam occurs when it reflects from the suspended optic if the angle of incidence is not zero and the optical lever beam is not centered on the mirror, as shown in the diagram in Figure 9. In the discussion that follows, we will compare the height of the reflected beam after traversing the optical lever arm distance onto a QPD without a receiving lens--such as was used in Initial LIGO--with the height at the QPD of the 13.6 m EFL receiver.

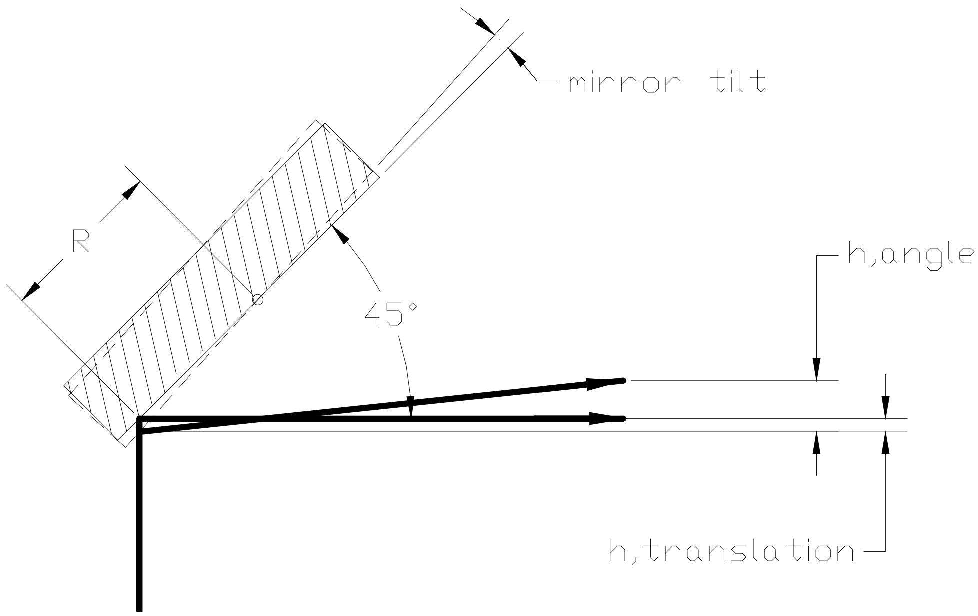

Figure 9: Angle to translation cross-coupling diagram

4.1.1.1.5.1 Cross-coupling with a bare QPD

We will assume the following parameters.

optlev beam offset from mirror rotation, mm	$R := \frac{380}{2}$	
mirror orientation angle, rad	$\theta_m := 45 \cdot \frac{\pi}{180}$	
mirror yaw tilt angle	$\theta_y := 0.75 \cdot 10^{-6}$	
optlev rec input angle	$\alpha_0 := 2 \cdot \theta_y$	$\alpha_0 = 1.5 \times 10^{-6}$
distance to oplev QPD	$L := 1800$	

The height of the beam at the optlev receiver caused by translation of the optlev beam is given by the following expression,

$$h_0 := R \cdot \theta_y \cdot \sin(\theta_m)$$

The cross-coupling error fraction with the lens-less QPD is defined by the following expression,

$$E_{qpd} := \frac{h_0}{L \cdot \alpha_0}$$

$$E_{qpd} = 0.037$$

4.1.1.1.5.2 Cross-coupling with 13.6 m EFL optlev receiver lens

The cross-coupling error fraction with the 13.6 m optlev receiver with the same mirror conditions can be determined from the following expression with reference to Figure 8.

$$E_{oplev4} := \frac{h_{qpd}(\Delta_{obj}, h_0, \alpha_0) - h_{qpd}(\Delta_{obj}, 0, \alpha_0)}{h_{qpd}(\Delta_{obj}, 0, \alpha_0)}$$

$$E_{oplev4} = 1.232 \times 10^{-5}$$

We see that the optlev receiver design has a negligible cross-coupling error compared to the lens-less QPD design.

This meets the requirement 3.1.1.5.

4.1.1.2 Optical Lever System Physical Characteristics

4.1.1.2.1 Initial LIGO Optical Lever

A drawing of the Initial LIGO optical lever transmitter and receiver assembly mounted to the support pedestal is shown in Figure 10 (D970190-B Optical Lever Assembly MMT3). The optical lever transmitters and receivers are mounted kinematically to support structures outside the vacuum chambers to provide stability. The support structures are bolted to the facility floor through kinematic intermediate mounting plates. This allows the support structures to be removed for access to chamber doors and subsequently replaced with minimum loss of pointing alignment. The optical levers for the BS and for the folded IFO FM in Initial LIGO were mounted to brackets welded to the BSC chamber SEI support pillars.

The optical lever support pedestals from Initial LIGO and the proposed arbor support structures (Figure 13) will be mounted kinematically to a rigid support plate on the floor so that they may be removed temporarily for access to the chambers and replaced subsequently with minimum loss of pointing alignment.

The lens-less QPD detector assembly used in Initial LIGO is shown in Figure 11 (D970156-B Position Detector Assy Optical Lever). The input steering mirror (12) of the QPD detector is motorized for remote alignment. The QPD is a Silicon quadrant photodiode, QD100-0.

The optical lever transmitter used in Initial LIGO is shown in Figure 12 (D970102-B 10X Light Source Assy Optical Lever). The output steering mirror (14) of the transmitter is motorized for remote alignment. The optical lever transmitter uses a commercial, fiber-coupled diode laser (wavelength 635 nm – 670 nm).

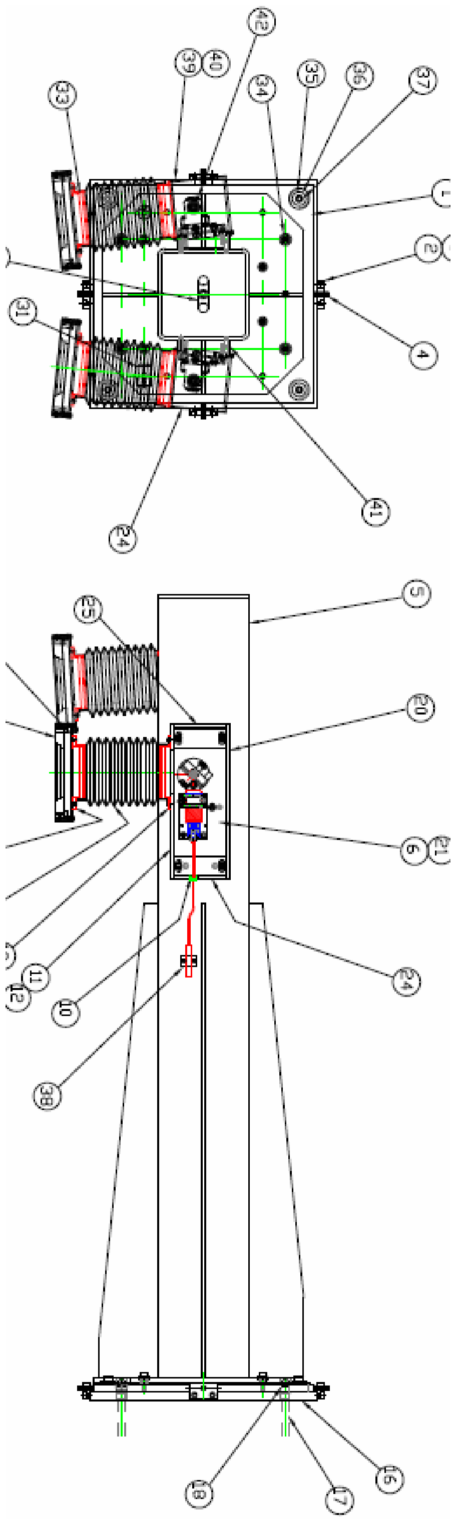

Figure 10: Optical Lever assembly mounted to pedestal

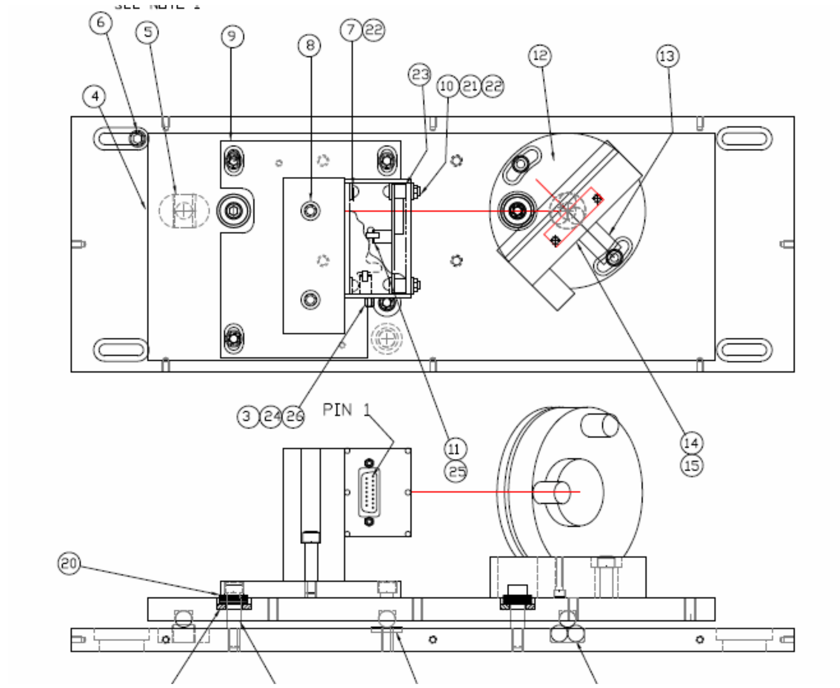

Figure 11: Lens-less QPD detector assembly

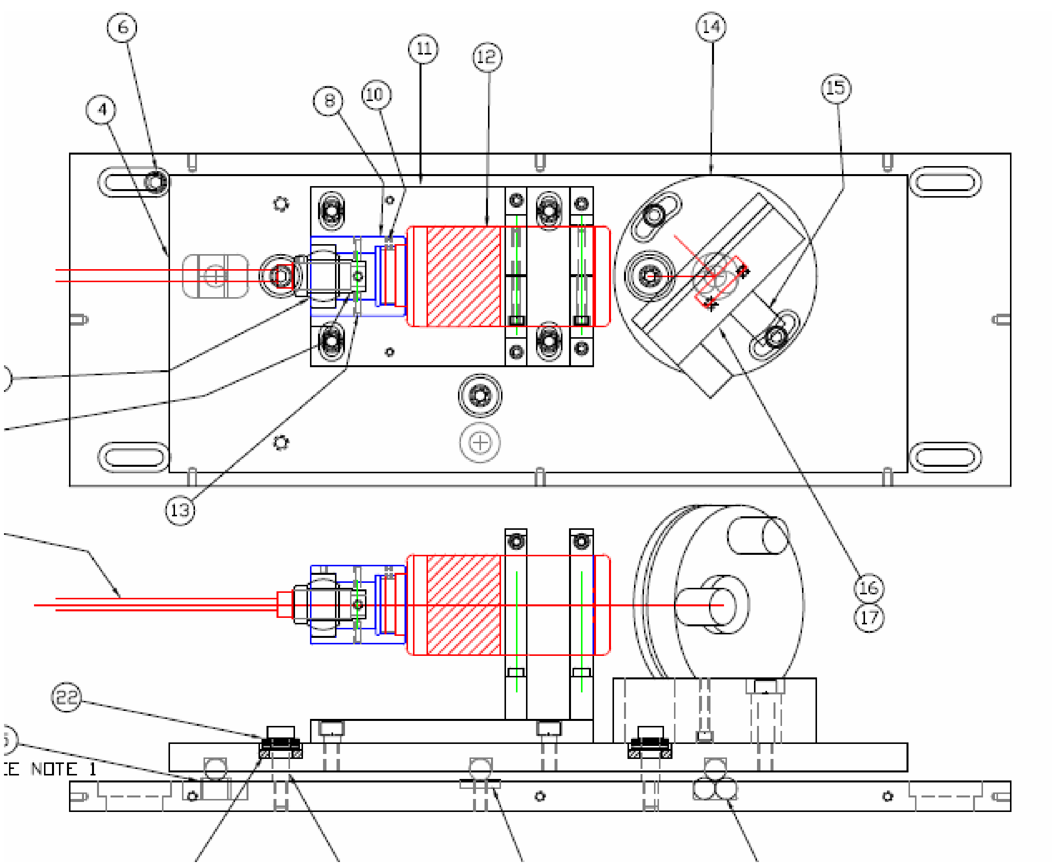

Figure 12: Optical Lever Transmitter assembly

The existing optical levers from Initial LIGO for the ITMs, which have 35 m lever arms, will be re-used in their existing location. Other existing Initial LIGO optical levers will be moved and re-used as necessary.

4.1.1.2.2 New optical lever transmitter and receiver lens modules

The new optical lever transmitter will be similar to the Initial LIGO design, except for 1) a different beam expanding telescope for creating the optimum spot size at the receiver QPD, and 2) the addition of the OPLEV4 receiver lens assembly. The new receiver assembly will be slightly larger than Initial LIGO, with room to accommodate the OPLEV4 receiver lens assembly shown in Figure 5.

4.1.1.2.3 Electrical characteristics

The optical lever transmitter uses a commercial diode laser with an integral power supply, cooling and intensity control. The power supply requires 110VAC @ TBD A.

The QPD requires regulated 15VDC @ TBD A.

The motorized steering mirrors for the optical transmitter and receiver modules use New Focus Picomotor actuators, which are activated by an electronic driver circuit from New Focus.

The Optical Lever Receiver output data consists of four analog voltage signals, one from each quadrant of the quadrant photodiode (QPD), buffered by transimpedence op amps. The signals appear at the pins of a 16 pin D connector on the end of the optical lever receiver QPD module.

4.1.1.2.4 New Manifolds with viewports

Many of the suspended optics are located in HAM2, HAM3, HAM4, and HAM5. New manifolds and beam tubes will be placed between HAM2-HAM3, and between HAM4-HAM5 with twelve additional pairs of viewports for each of the IO section and the Output section. The new manifold between HAM2-HAM3 is shown in Figure 13. The transmitter and receiver modules will be mounted to the arbor-shaped support structure that straddles the spool piece connecting the manifold to the HAM chambers, as shown for the MMT3 optlev in Figure 14.

Flexible bellows enclose the laser beams between the trans/rec modules and the viewports to limit access for providing laser safety, as well as for shielding the trans/rec modules from airborne particulates.

4.1.1.2.5 Steering mirrors for optical lever beams

In-vacuum steering mirrors will be needed for some of the suspended optics in order for the optical lever beams to hit the mirror surface, e.g. the optical lever beams for the MC3 and MMT3 mirrors, as shown in Figure 15. Note that this is an extreme example, showing the need for three steering mirrors for incidence of the optical lever beams on MC3. Two steering mirrors are needed to obtain incidence on MC2, as shown in Figure 16.

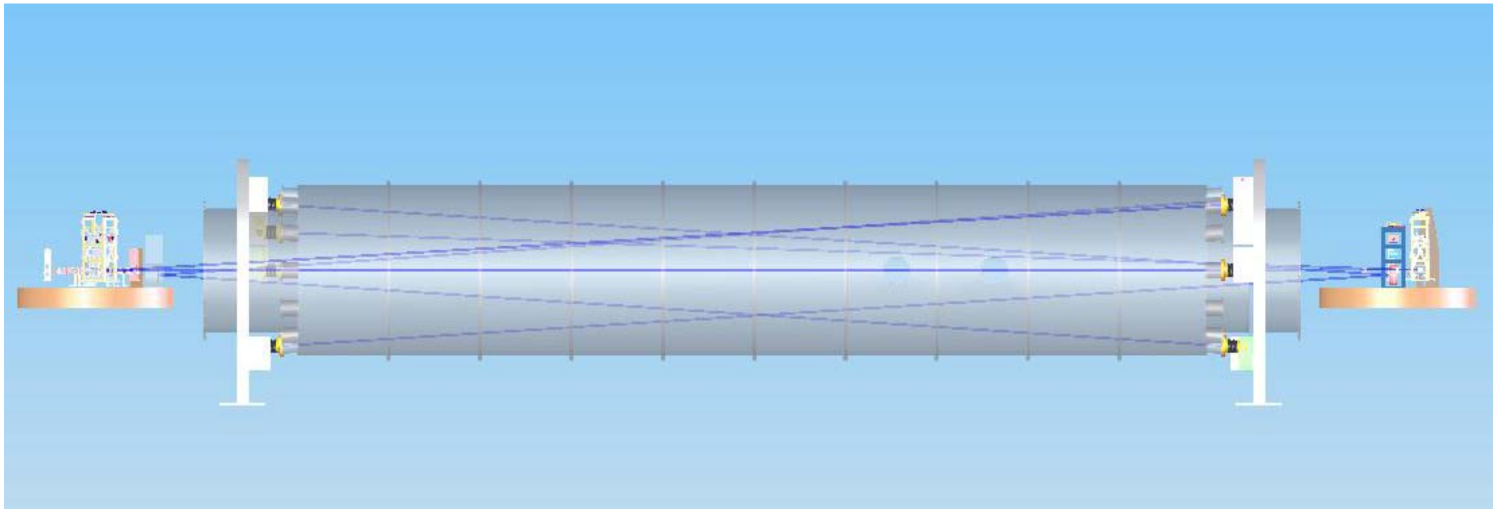

Figure 13: IO manifold and beam tube between HAM2 and HAM3

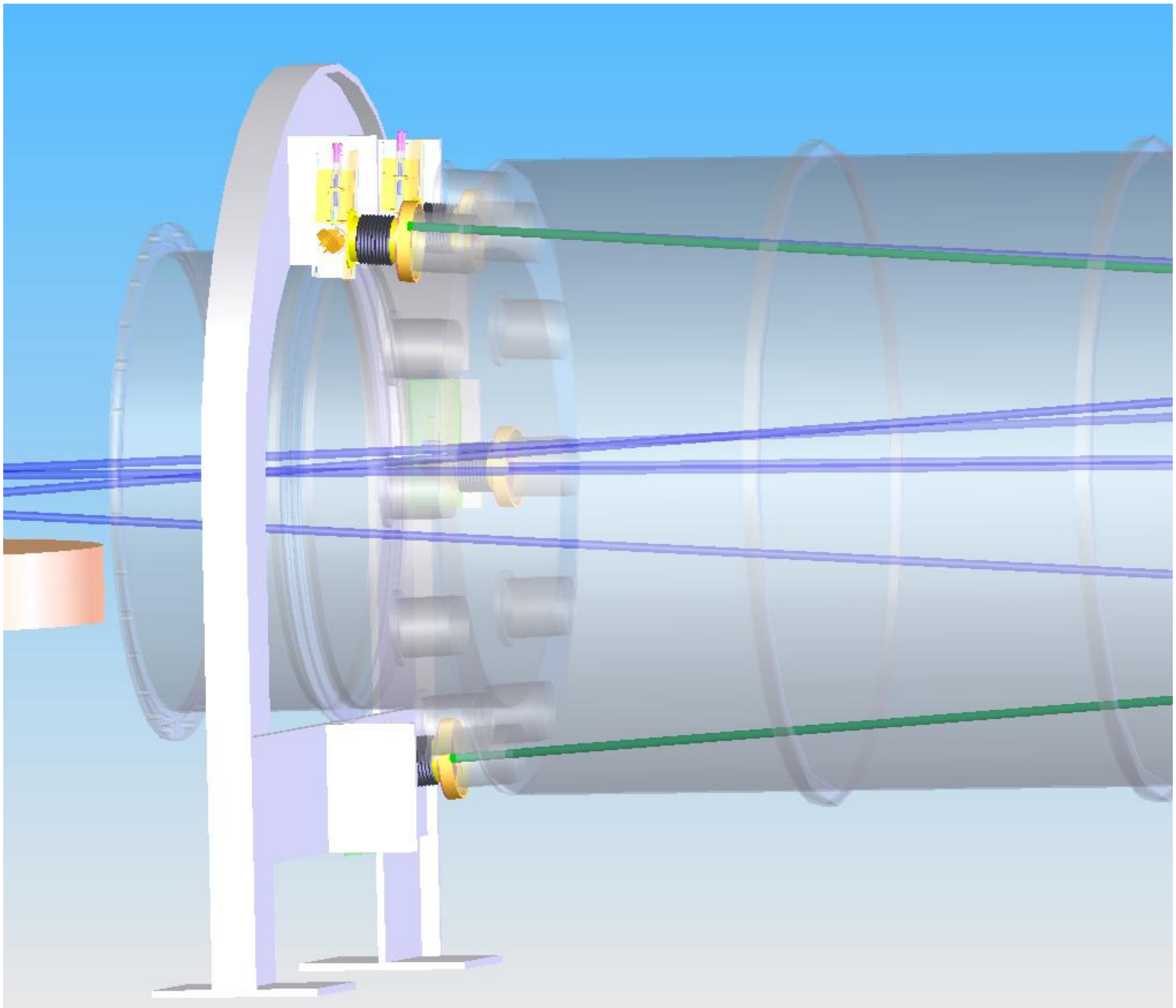

Figure 14: Optlev transmitter and receiver modules for MMT3

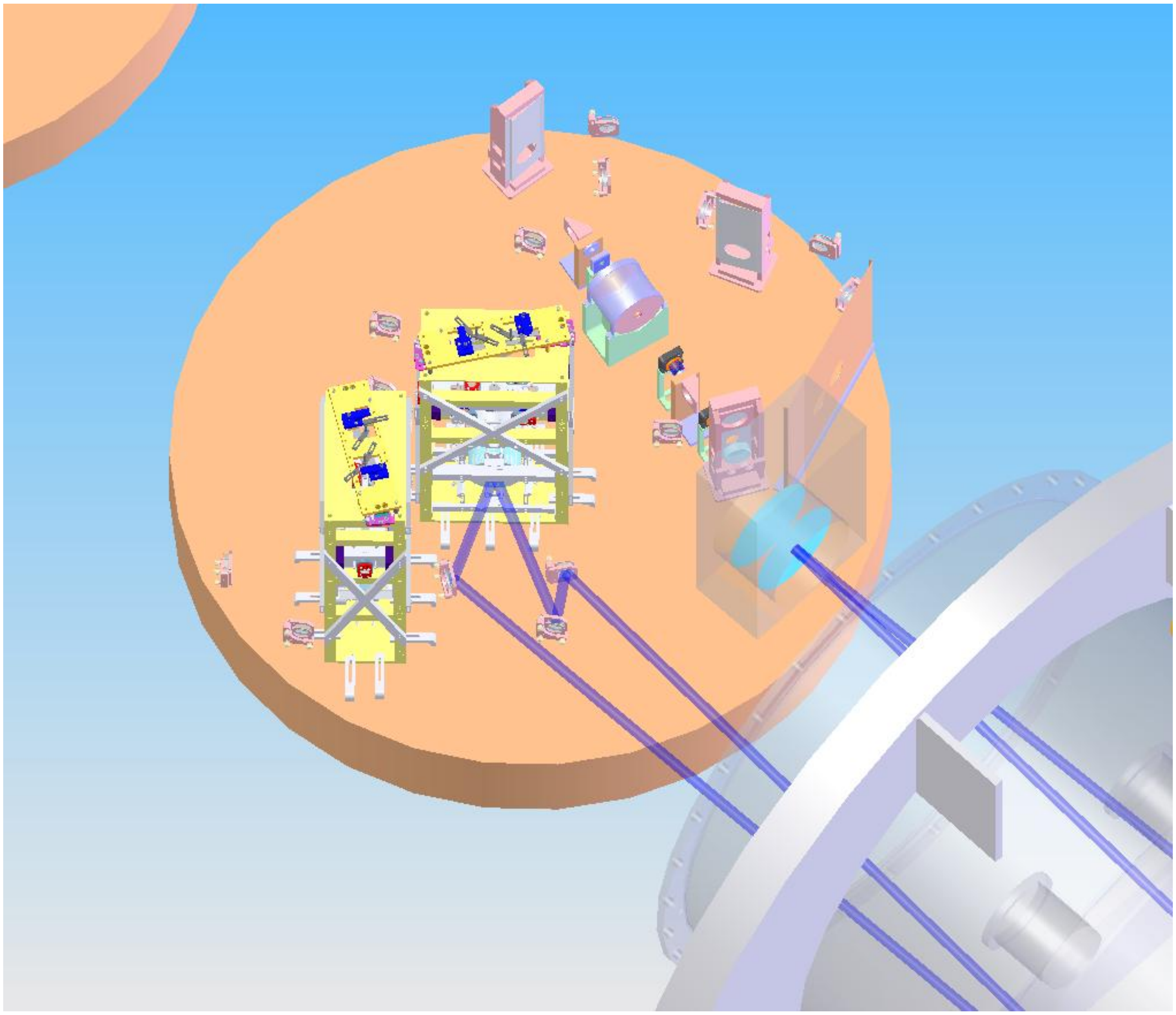

Figure 15: Optical lever beams for MC3 and MMT3

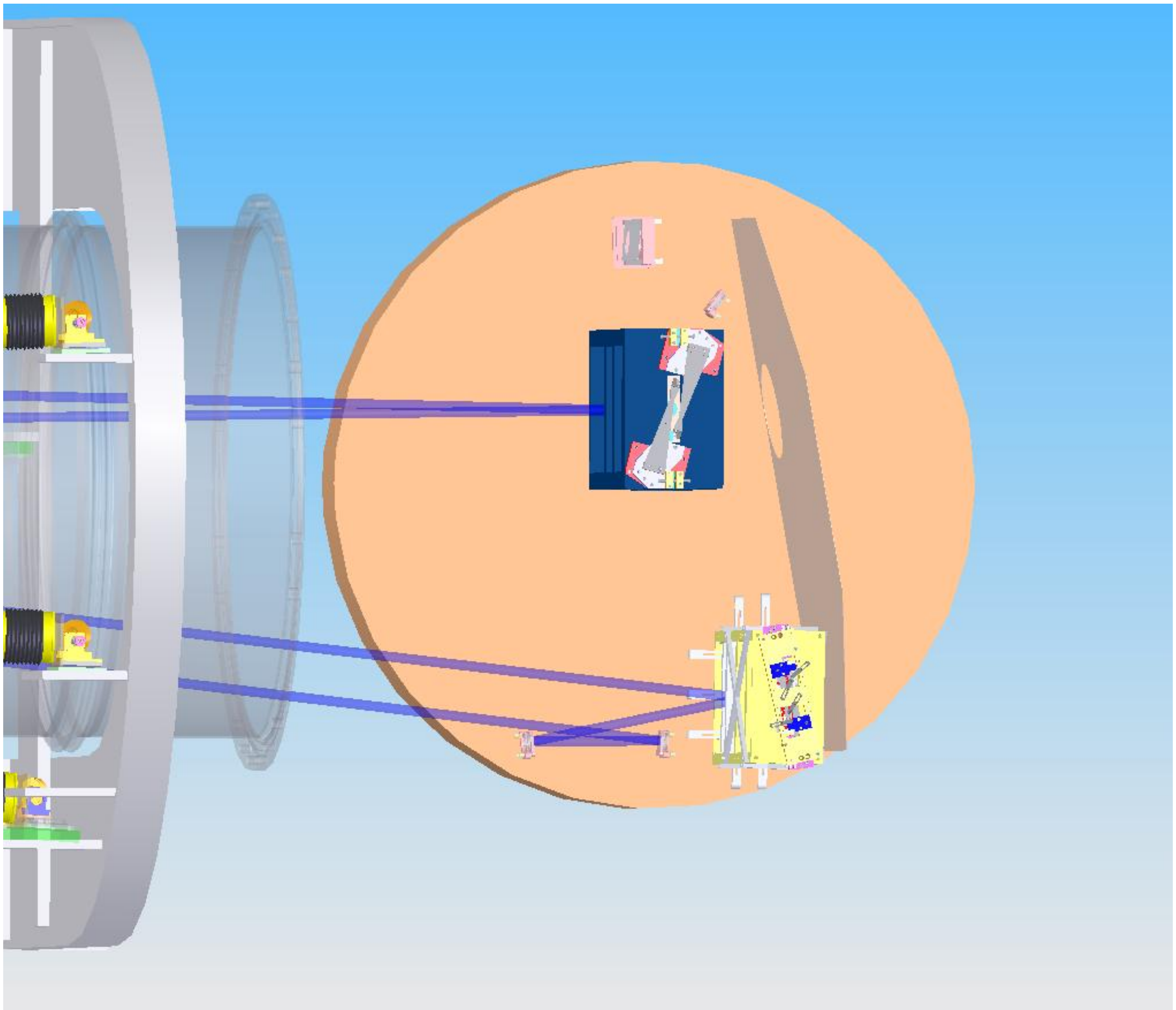

Figure 16: MC2 optical lever beams

4.1.1.3 Optical Lever System Interface Definitions

4.1.1.3.1 Interfaces to other LIGO detector subsystems

4.1.1.3.1.1 Mechanical Interfaces

The optical lever support structures will be bolted rigidly to the floor of the facility.

The optical lever beam will pass through vacuum viewports that are attached to the HAM and BSC chambers.

A flexible bellows will attach to the vacuum chamber and enclose the optical path between each optical lever transmitter/receiver and the viewport.

4.1.1.3.1.2 Electrical Interfaces

CDS will provide line voltage for the optical lever laser power supply and regulated 15 VDC electrical power for the QPD receiver circuit.

CDS will provide an analog signal cable for the four QPD output voltages plus an isolated ground. The CDS signal cable will have a compatible connector for connecting to the QPD output connector.

4.1.1.3.1.3 Optical Interfaces

AOS baffles will allow adequate clearance for optical lever beams.

4.1.1.3.1.4 Stay Clear Zones

The stay clear zones for the optical levers are defined by the flexible bellows between the optical lever transmitters and receivers and the viewports on the vacuum chambers.

The mounting pedestals and mounting arbors will not interfere with the piping beneath the beam tubes and manifolds.

4.1.1.3.2 Interfaces external to LIGO detector subsystems

4.1.1.3.2.1 Mechanical Interfaces

4.1.1.3.2.2 Electrical Interfaces

4.1.1.3.2.3 Stay Clear Zones

4.1.1.4 Optical Lever System Reliability

4.1.1.4.1 Mean Time Before Failure

Get data from Doug Cook

TBD--Optical lever laser sources are to have a MTBF of 10,000 hours.

This meets the requirement 3.1.1.4.

4.1.1.4.2 Optical Lever System Maintainability

The following components are susceptible to failure:

1) Diode laser source assembly.
2) Motorized optic mount.
3) Photodiode assembly.

Each of these items will have plug connections and will be replaceable if necessary for maintenance.

The laser is connected with a removable connector to a fiber cable with an integral GRIN output collimator, which is mounted in alignment with the beam expander. The laser can be disconnected from the fiber for replacement of a failed laser without disturbing the preset head alignment and therefore with minimum compromise of the pointing of the optical lever beam.

Re-alignment of the laser source and photodiode calibration can be accomplished in less than 1 day.

This meets the requirement 3.1.1.6.

4.1.1.4.3 Optical Lever System Environmental Conditions

4.1.1.4.3.1 Natural Environment

4.1.1.4.3.1.1 Temperature and Humidity

The optical levers are designed to operate in the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 2 Environmental Performance Characteristics

Operating	Non-operating (storage)	Transport
+20C to +25C, 20-70% RH, non- condensing	0C to +60C, 10-90% RH, non-condensing	0C to +60C, 10-90% RH, non- condensing

4.1.1.4.3.1.2 Atmospheric Pressure

The Optical Lever System shall function under normal atmospheric pressure conditions

4.1.1.4.3.1.3 Seismic Disturbance

The optical lever transmitters and receivers will be mounted rigidly to the LIGO facility floor and will be subjected to the ambient seismic disturbances.

4.1.1.4.3.2 Induced Environment

4.1.1.4.3.2.1 Electromagnetic Radiation

The Micro Laser Systems, Inc. diode laser is compliant with the standards CDRH 21 CFR1040.10 and IEC 60825-1.2. However, it may not meet the requirement 3.1.1.7. The subsystem will also comply with LIGO-E960036-A LIGO EMI Control Plan and Procedures.

4.1.1.4.3.2.2 Acoustic

The optical lever subsystem does not contain moving parts and will not cause acoustic noise.

4.1.1.4.3.2.3 Mechanical Vibration

The optical lever subsystem does not contain moving parts and will not cause vibration.

4.1.1.5 Optical Lever System Transportability

All items will be transportable by commercial carrier without degradation in performance. As necessary, provisions will be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation will be utilized to prevent damage. The mounting pedestals and arbors will be movable by forklift, and will have appropriate lifting eyes and mechanical strength to be lifted by cranes.

4.1.2 Optical Lever System Design and Construction

The optical lever system is designed and constructed to maintain long-term pointing stability.

4.1.2.1 Materials and Processes

4.1.2.1.1 Finishes

All materials will have a non-shedding external finish to protect them from corrosion.

4.1.2.1.2 Component Naming

All components will be identified using the E950111-A LIGO Naming Convention. This will include identification (part or drawing number, revision number, serial number) physically stamped on all components, in all drawings and in all related documentation.

4.1.2.2 Workmanship

All components will be manufactured according to good commercial practice.

4.1.2.3 Interchangeability

Common elements with ordinary dimensional tolerances will be interchangeable.

4.1.2.4 Safety

This item will meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis will be conducted in accordance with guidelines set forth in M950046-F LIGO Project System Safety Management Plan, section 3.3.2.

4.1.2.5 Human Engineering

Not applicable.

4.1.3 Assembly and Maintenance

Optical levers will be calibrated per T990026-00 Calibration of Optical Levers. Assembly procedures will be developed in conjunction with the optical lever hardware design.

4.1.4 Documentation

The documentation will consist of working drawings, assembly drawings, alignment procedures, and manufacturer's data sheets wherever applicable.

4.1.4.1 Specifications

The manufacturer's specifications for the diode laser and the QPD will apply.

4.1.4.2 Design Documents

Revised drawings and calibration documents will be produced as necessary.

4.1.4.3 Engineering Drawings and Associated Lists

A complete set of drawings suitable for fabrication will be provided along with Bill of Material (BOM) and drawing tree lists. The drawings will comply with LIGO standard formats and shall be provided in electronic format. All documents shall use the LIGO drawing numbering system, be drawn using LIGO Drawing Preparation Standards.

4.1.4.4 Technical Manuals and Procedures

4.1.4.4.1 Procedures

Procedures will be provided for, at minimum,

- Initial installation and setup of equipment
- Normal operation of equipment
- Normal and/or preventative maintenance
- Installation of new equipment
- Troubleshooting guide for any anticipated potential malfunctions

4.1.4.4.2 Manuals

All manufacturers's operating and installation manuals will be supplied in addition to LIGO calibration procedures.

4.1.4.5 Documentation Numbering

All documents will be numbered and identified in accordance with the LIGO documentation control numbering system LIGO document TBD

4.1.4.6 Test Plans and Procedures

All test plans and procedures will be developed in accordance with the LIGO Test Plan Guidelines, LIGO document. TBD.

4.1.5 Logistics

The design will include a list of all recommended spare parts and special test equipment required.

4.1.6 Precedence

4.1.7 Qualification

Optical levers will be calibrated per T990026-00 Calibration of Optical Levers.

4.2 Viewports

Various types of viewports are used for providing access to optical beams into and out of the IFO. Video camera viewports are used to provide a visible access from outside the chambers for video cameras to view the IFO optics. Optical lever viewports are used to provide entry and exit for optical lever beams from outside the chambers to measure the tilt of the IFO suspended optics. Illumination viewports are used to provide illumination of the vacuum chambers with an outside illumination lamp. ZnSe viewports are used to provide transmission of CO2 laser beams for heating certain core optics. Hartmann viewports are used to provide entry and exit ports for the Hartmann wavefront sensing beams.

4.2.1 Viewport System Characteristics

4.2.1.1 Viewport Performance Characteristics

The viewports will have antireflection coatings to provide high transmissivity at the appropriate wavelengths. The optical quality of the viewports will not significantly degrade the resolution of the video cameras and of the TCS heating pattern. The Brewster's angle viewports will have low scattering and reflection losses @ 1064 nm wavelength.

4.2.1.2 Viewport Physical Characteristics

4.2.1.2.1 Video Camera Viewport

The video camera viewport will be the same as was used for Initial LIGO--MDC VP-800, 5.4 in clear diameter, zero-length, Kovar-sealed viewport, made of Corning 7056 glass (L060068-00 ASC Vacuum Viewports). The experience of Initial LIGO showed that these video camera viewports maintained the resolution of the video cameras > 250 TV lines vertical and horizontal. This resolution was adequate for measuring the beam centroid with respect to the rim of the COC mirrors to a precision < 1 mm. This meets the requirement 3.2.1.1.

The viewport will be AR coated for minimum reflection @ 1064 nm (specified R<0.25% per surface at normal incidence). This meets the requirement 3.2.1.2.

The viewport is designed to be a vacuum sealing viewport. This meets the requirement 3.2.1.3.

A special TCS camera viewport for viewing the projected aiming cross on the heated optic is mounted to a modified double window 10 in Nor Cal conflat (P/N 031111-1-01) in the same camera housing with the TCS ZnSe viewport, item 1 in Figure 17. This also meets the requirements of 3.2.1.

4.2.1.2.2 Illuminator Viewport

The illuminator viewport will be the same as the camera viewport, except without an AR coating. This meets the requirements 3.2.2.1 and 3.2.2.2.

4.2.1.2.3 Optical Lever Viewport

The optical lever viewport for the A1 and A7 flange nozzles, and for the nozzles in the new IO manifold and the new OUT manifold will be MDC VP-800 clear diameter zero-length Kovar-sealed viewport designed for vacuum sealing, made of Corning 7056 glass, the same as the video camera viewport. The viewport will have an AR coating @ 635 nm or @ 1064, normal incidence with a specified total reflectivity < 0.5%. This meets the requirements 3.2.3.1 and 3.2.3.2.

The optical lever viewport for the HAM and BSC chamber nozzles, where the optical lever beam may pass close to the inside edge of the viewport, will be fused silica viewport made by Insulator Seal P/N ISI 4.9722012 designed for vacuum sealing with 7.8in diameter clear aperture (L060068-00 ASC Vacuum Viewports). These viewports will be AR coated @ 635 nm with a specified total reflectivity < 0.5%. This meets the requirements 3.2.3.1 and 3.2.3.2.

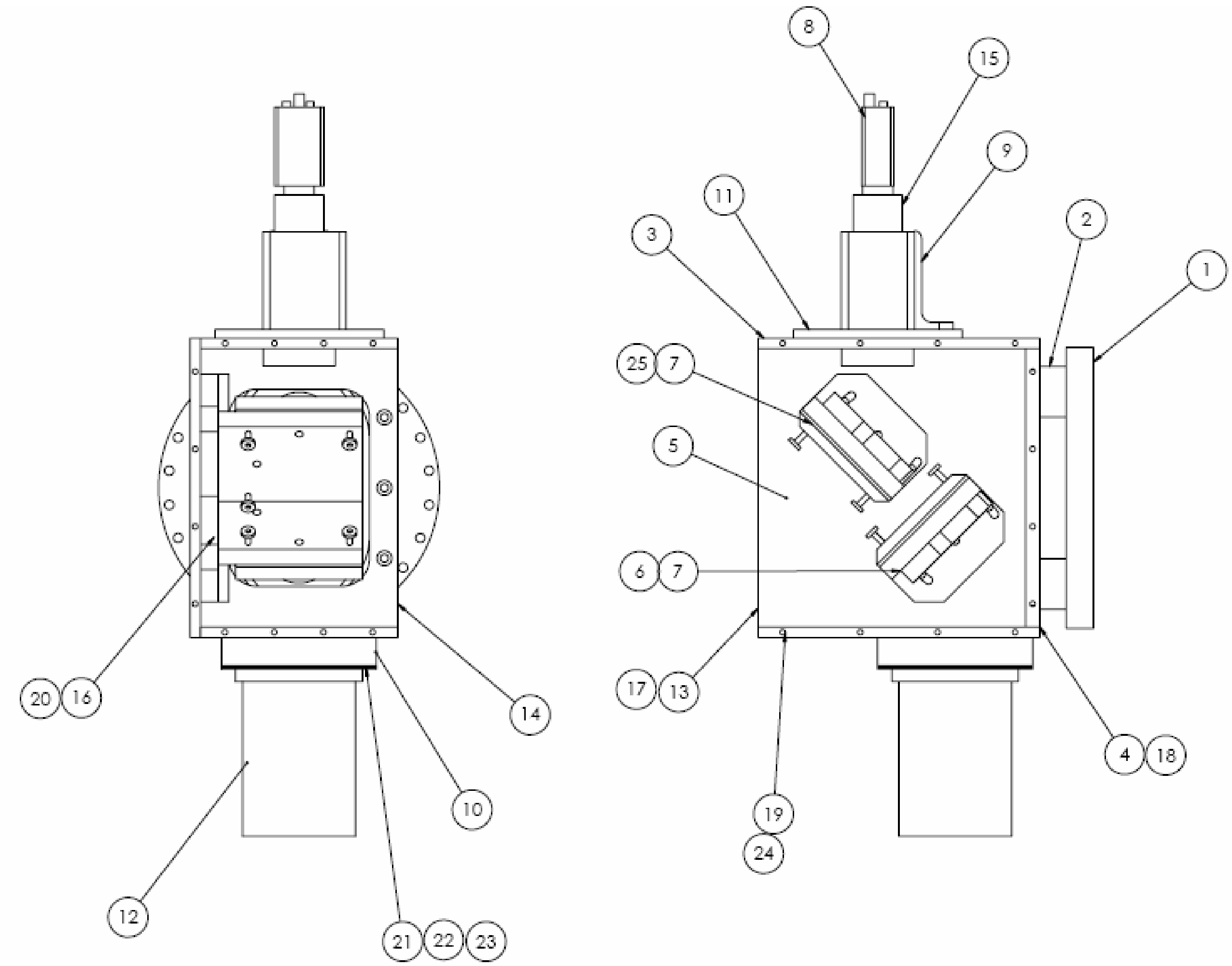

Figure 17: TCS camera housing

4.2.1.2.4 Brewster's Angle Viewport

A blank flange containing three nozzles sealed with viewports at Brewster's angle to minimize reflections and scattering, will be placed between HAM1 and HAM2 to separate the vacuum regions of the two chambers, as shown in the plan view of Figure 18. The 5.0 in diameter, 0.5 in thick viewports will be made of optical grade A fused silica and will be super-polished to ensure low surface scattering. This will meet the requirements 3.2.4.1, 3.2.4.2, 3.2.4.3 and 3.2.4.4.

Similarly, a blank flange with two nozzles will separate the vacuum regions of HAM5 and HAM6, as shown in Figure 19.

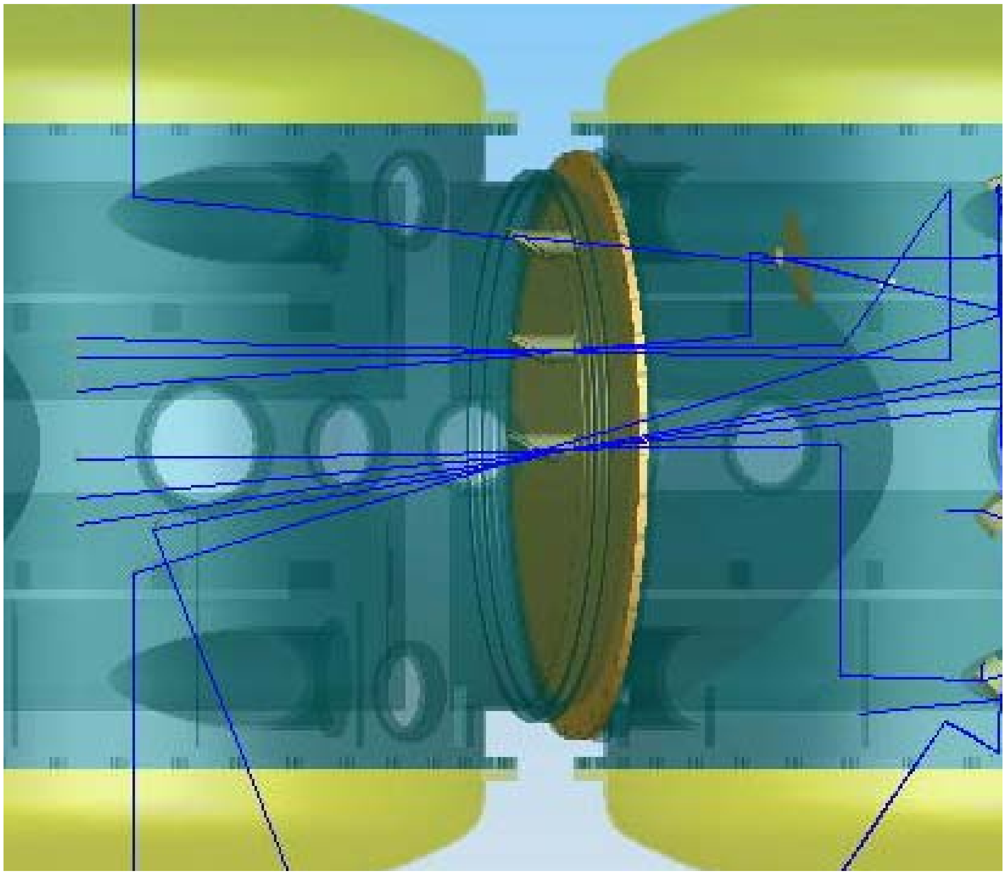

Figure 18: Blank flange with Brewster windows, H_1-2

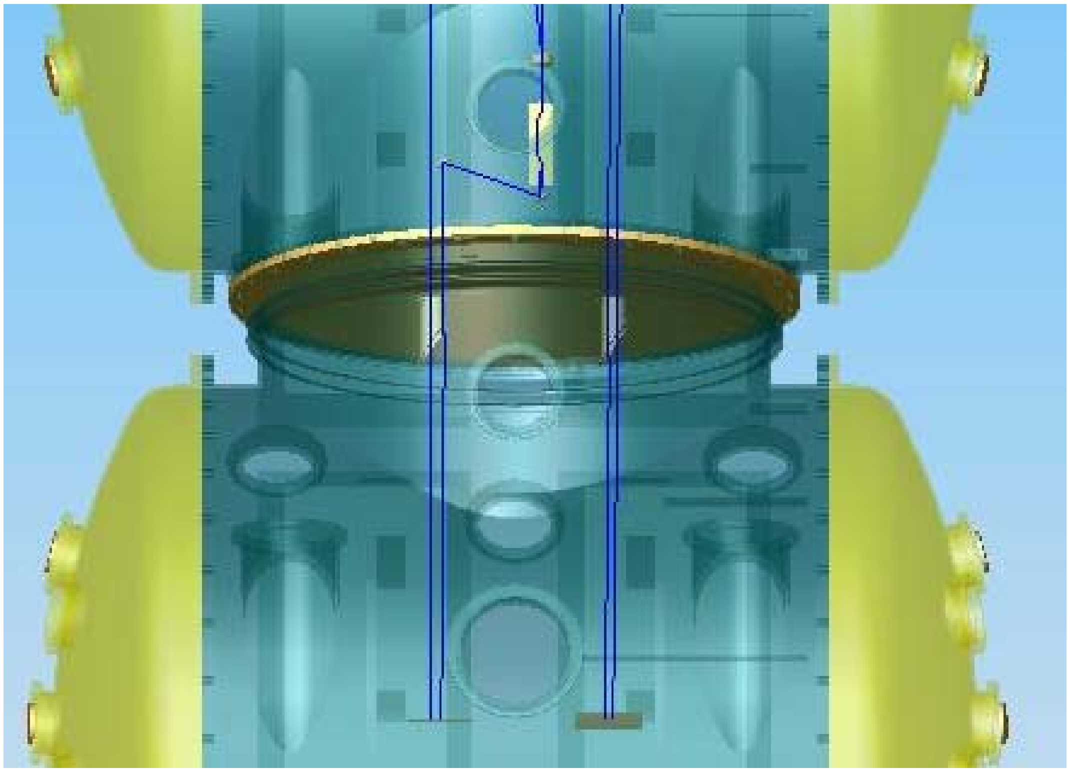

Figure 19: Blank flange with Brewster windows, H_5-6

4.2.1.2.5 TCS Viewport

The TCS ZnSe viewport is mounted in the same camera housing with the TCS video camera viewport for viewing the aiming cross on the heated optic, as shown in Figure 17.

The TCS viewport was used in Initial LIGO for vacuum sealing—P/N 414494 manufactured by II-VI Infrared from ZnSe, 3.0 in diameter by 0.5 in thick. This meets the requirement 3.2.5.4.

The ZnSe viewport has an AR coating, with a typical transmissivity @ 10.6 microns wavelength at normal incidence >99.5%, and >90% @ 635 nm. This meets the requirement 3.2.5.3.

The windows are optical quality with a maximum wavefront distortion of 1 wave @ 633nm wavelength. This meets the requirement 3.2.5.2.

The surface quality is 20-10 scratch-dig. This meets the requirement 3.2.5.1.

4.2.1.2.6 Hartmann Viewport

The viewports for the Hartmann beams will be the same as were used for the PO beams in Initial LIGO (see E990086-B Component Specification: COS viewport Window)--2.75 in clear aperture, optical grade-A fused silica. The viewports will have a 10-5 laser quality surface finish and will be AR coated at the Hartmann beam wavelength for >99.5% transmissivity. This meets the requirements 3.2.6.1, 3.2.6.2, 3.2.6.3, and 3.2.6.4.

4.2.1.2.7 PSL Viewport

The viewport for introducing the PSL beam into the IFO at HAM2 will be a super-polished, low scattering fused silica window with AR coating @ 1064 nm (see specification E990086-B

Component Specification: COS viewport Window), the same as was used for the APS output beam in Initial LIGO. This meets the requirements of 3.2.7.

4.2.1.2.8 Summary of Viewport Types and Locations

A summary of the various viewport types and their locations is shown in Table 4.

4.2.1.3 Viewport Interface Definitions

4.2.1.3.1 Interfaces to other LIGO detector subsystems

The viewports are mounted onto vacuum flanges that mount to the existing nozzles on the HAM and BSC chambers, and to the viewport nozzles that are attached to the manifolds between vacuum chambers.

4.2.1.3.1.1 Stay Clear Zones

The optical path of the light beams passing from the optical lever transmitters and receivers, and to the video cameras will be enclosed by a suitable means to define the stay clear zone.

4.2.1.4 Viewport Reliability

4.2.1.4.1 Mean Time Before Failure

Viewports are durable optical components that have an essentially unlimited lifetime.

4.2.1.4.2 Optical Lever System Maintainability

The viewports will be handled and maintained using industry standard optical surface cleaning procedures and protocols. They will be replaced if necessary.

4.2.1.4.3 Optical Lever System Environmental Conditions

4.2.1.4.3.1 Natural Environment

4.2.1.4.3.1.1 Temperature and Humidity

The viewports are designed to function with vacuum conditions on the inside surface, and with the humidity and temperature controlled environment of the enclosed LIGO LVEA on the outer surface.

Table 3 Environmental Performance Characteristics

Operating	Non-operating (storage)	Transport
+20C to +25C, 20-70% RH, non- condensing	0C to +60C, 10-90% RH, non-condensing	0C to +60C, 10-90% RH, non- condensing

4.2.1.4.3.1.2 Atmospheric Pressure

The viewports are designed to function with a differential pressure between faces of one atmospheric pressure.

Table 4: Viewport types and locations

IFO	SIGNAL BEAM	OPTICAL LEVER	VIDEO CAMERA	ILLUM	CO2 HEAT	HARTMANN	CHAMBER	NOZZLE	VP PART
Non-folded									
	MC trans						BLANK H_1-2	Brew2	5.0 BREWSTER
	IO Faraday monitor 2						BLANK H_1-2	Brew2	5.0 BREWSTER
	IO Faraday monitor 3						BLANK H_1-2	Brew2	5.0 BREWSTER
	IO Faraday monitor 1						BLANK H_1-2	Brew3	5.0 BREWSTER
	REFL						BLANK H_1-2	Brew3	5.0 BREWSTER
	MC REFL						BLANK H_1-2	Brew3	5.0 BREWSTER
	OMMT OUT						BLANK H_5-6	Brew1	5.0 BREWSTER
	BSPO						BLANK H_5-6	Brew2	5.0 BREWSTER
	ITMXPO						BLANK H_5-6	Brew2	5.0 BREWSTER
	PSL						HAM2	VP4	COS type2
		MMT1 optlev out					HAM1	VP2	OPTLEV 7.8 DIA, ISI 4.9722012
		SM1 optlev out					HAM1	VP5	OPTLEV 7.8 DIA, ISI 4.9722012
		SM2 optlev out					HAM1	VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		MMT1 optlev in					BLANK H_1-2	Brew1	5.0 BREWSTER
		SM1 optlev out					BLANK H_1-2	Brew3	5.0 BREWSTER
		MMT3 optlev in					IO MANIFOLD	+X VP1	OPTLEV 7.8 DIA, ISI 4.9722012
		MMT3 optlev out					IO MANIFOLD	+X VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		PRM optlev in					IO MANIFOLD	-X VP11	OPTLEV 7.8 DIA, ISI 4.9722012
		PRM optlev out					IO MANIFOLD	-X VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		MC2 optlev in					IO MANIFOLD	-X VP9	OPTLEV 7.8 DIA, ISI 4.9722012
		MC2 optlev out					IO MANIFOLD	-X VP10	OPTLEV 7.8 DIA, ISI 4.9722012
		MC3 optlev in					IO MANIFOLD	+X VP9	OPTLEV 7.8 DIA, ISI 4.9722012

		MC3 optlev out					IO MANIFOLD	+X VP11	OPTLEV 7.8 DIA, ISI 4.9722012
		MMT2optlev in					IO MANIFOLD	-X VP2	OPTLEV 7.8 DIA, ISI 4.9722012
		MMT2 optlev out					IO MANIFOLD	-X VP3	OPTLEV 7.8 DIA, ISI 4.9722012
		MC1 optlev in					HAM2	VP5	OPTLEV 7.8 DIA, ISI 4.9722012
		MC1 optlev out					HAM2	VP12	OPTLEV 7.8 DIA, ISI 4.9722012
		SM2 optlev in					HAM2	VP13	OPTLEV 7.8 DIA, ISI 4.9722012
		SM1 optlev in					HAM2	VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		BSPO M2 optlev in					HAM4	VP4	OPTLEV 7.8 DIA, ISI 4.9722012
		BSPO M2 optlev out					HAM4	VP4	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT3 optlev in					HAM5	VP3	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT3 optlev out					HAM5	VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		SRM optlev in					OUT MANIFOLD	-Y VP7	OPTLEV 7.8 DIA, ISI 4.9722012
		SRM optlev out					OUT MANIFOLD	-Y VP12	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT2 optlev in					OUT MANIFOLD	-Y VP6	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT2 optlev out					OUT MANIFOLD	-Y VP11	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT1 optlev in					OUT MANIFOLD	+Y VP9	OPTLEV 7.8 DIA, ISI 4.9722012
		OMMT1 optlev out					OUT MANIFOLD	+Y VP3	OPTLEV 7.8 DIA, ISI 4.9722012
		BSPO M1 optlev in					BSC1	VP9	OPTLEV 7.8 DIA, ISI 4.9722012
		BSPO M1 optlev out					BSC1	VP11	OPTLEV 7.8 DIA, ISI 4.9722012
		ITMY1 optlev in					A1-B FLANGE	VP4	OPTLEV 5.4 DIA VP800-AR635
		ITMY1 optlev out					A1-B FLANGE	VP1	OPTLEV 5.4 DIA VP800-AR635
		ITMX1 optlev in					A1-A FLANGE	VP4	OPTLEV 5.4 DIA VP800-AR635
		ITMX1 optlev out					A1-A FLANGE	VP1	OPTLEV 5.4 DIA VP800-AR635
		ETMX1 optlev in					A-7A FLANGE	VP3	OPTLEV 5.4 DIA VP800-AR635
		ETMX1 optlev out					A-7A FLANGE	VP6	OPTLEV 5.4 DIA VP800-AR635

		ETMY1 optlev in					A-7B FLANGE	VP3	OPTLEV 5.4 DIA VP800-AR635
		ETMY1 optlev out					A-7B FLANGE	VP6	OPTLEV 5.4 DIA VP800-AR635
			MMT3 video				IO MANIFOLD	+X VP10	VIDEO, 5.4 DIA VP800-AR1064
			MMT2 TCS video				HAM2	VP1	COS type1
			SM1/MC3 video				HAM2	VP6	VIDEO, 5.4 DIA VP800-AR1064
			PRM, MMT2 & MC2 video				HAM3	VP1	VIDEO, 5.4 DIA VP800-AR1064
			MMT3 TCS video				HAM3	VP2	COS type1
			ITMY video				BSC1	VP2	VIDEO, 5.4 DIA VP800-AR1064
			CPY TCS video				BSC1	S-VP5	COS type1
			BS video				BSC2	VP9	COS type1
			ITMX video				BSC3	VP8	VIDEO, 5.4 DIA VP800-AR1064
			CPX TCS video				BSC3	S-VP2	COS type1
			ETMX video				BSC9	VP2	VIDEO, 5.4 DIA VP800-AR1064
			TRANSMON X				BSC9	VP8	VIDEO, 5.4 DIA VP800-AR1064
			ETMY video				BSC10	VP2	VIDEO, 5.4 DIA VP800-AR1064
			TRANSMON Y				BSC10	VP8	VIDEO, 5.4 DIA VP800-AR1064
				HAM1			HAM1	VP1	ILLUM, 5.4 DIA VP800/450009
				HAM2			HAM2	VP2	ILLUM, 5.4 DIA VP800/450009
				HAM3			HAM3	VP3	ILLUM, 5.4 DIA VP800/450009
				HAM4			HAM4	VP1	ILLUM, 5.4 DIA VP800/450009
				HAM5			HAM5	VP5	ILLUM, 5.4 DIA VP800/450009
				HAM6			HAM6	VP5	ILLUM, 5.4 DIA VP800/450009
				BSC1			BSC1	VP5	ILLUM, 5.4 DIA VP800/450009
				BSC2			BSC2	VP11	ILLUM, 5.4 DIA VP800/450009
				BSC3			BSC3	VP2	ILLUM, 5.4 DIA VP800/450009
				BSC9			BSC9	VP11	ILLUM, 5.4 DIA VP800/450009
				BSC10			BSC10	VP11	ILLUM, 5.4 DIA

									VP800/450009
					CO2 beam MMT2		HAM2	VP1	3.0 ZnSe
					CO2 beam MMT3		HAM3	VP2	3.0 ZnSe
					CO2 beam CPY		BSC1	VPS4	3.0 ZnSe
					CO2 beam BS		BSC2	VP9	3.0 ZnSe
					CO2 beam CPX		BSC3	VPS2	3.0 ZnSe
						ITMX RC HARTMANN	HAM4	VP5	COS type1
						ITMY RC HARTMANN	HAM4	VP6	COS type1
						ITMYHR HARTMANN	BSC1	VP10	COS type1
						BS HARTMANN	BSC2	VP2	COS type1
						ITMXHR HARTMANN	BSC3	VP10	COS type1
						ETMX HARTMANN	BSC9	VPS2	COS type1
						ETMY HARTMANN	BSC10	VPS2	COS type1

4.2.1.5 Viewport Transportability

All items will be transportable by commercial carrier without degradation in performance. As necessary, provisions will be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation will be utilized to prevent damage. All containers shall be movable by forklift.

4.2.2 Viewport Design and Construction

4.2.2.1 Materials and Processes

The in-vacuum materials and processes used in the fabrication of the viewports will be compatible with the LIGO approved materials list.

4.2.2.1.1 Materials

A list of currently approved materials for use inside the LIGO vacuum envelope can be found in E960022-B LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures. All materials used inside the vacuum chamber will comply with LIGO-E960022-00-D.

4.2.2.1.2 Processes

4.2.2.1.2.1 Cleaning

All materials used inside the vacuum chambers will be cleaned in accordance with Specification Guidance for Seismic Component Cleaning, Baking, and Shipping Preparation (LIGO-L970061-00-D).

4.2.2.1.3 Component Naming

All components will be identified using E950111-A LIGO Naming Convention. This will include identification (part or drawing number, revision number, serial number) physically stamped on all components, in all drawings and in all related documentation. The flange edges of the glass-to-metal sealed viewports will be marked to indicate the AR coating.

4.2.2.2 Workmanship

All components will be manufactured according to good commercial practice.

4.2.2.3 Interchangeability

Viewports with like dimensions will be interchangeable.

4.2.2.4 Safety

This item will meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements.

4.2.2.5 Human Engineering

Not applicable.

4.2.3 Assembly and Maintenance

Assembly installation/calibration documentation will be developed.

4.2.4 Documentation

4.2.4.1 Specifications

Manufacturer's specifications for MDC VP-800 series viewports, and Insulator Seal 9722012 series viewports; L980086-00 specification, and E990086 for COS viewports will apply.

4.2.4.2 Design Documents

Same as 4.2.4.1

4.2.4.3 Engineering Drawings and Associated Lists

Same as 4.2.4.1

4.2.4.4 Technical Manuals and Procedures

Not applicable.

4.2.4.5 Documentation Numbering

All documents will be numbered and identified in accordance with the LIGO documentation control numbering system LIGO document TBD

4.2.4.6 Test Plans and Procedures

A test plan and procedure will be developed for testing those viewports that use an o-ring for vacuum sealing to assure that the vacuum leak rate is acceptable.

4.2.5 Logistics

4.2.5.1 Spare Parts

TBD

4.2.5.2 Special Test Equipment

TBD

4.2.6 Precedence

4.2.7 Qualification

4.3 Video Cameras

Video cameras are used to view the vacuum chamber interiors during Initial Alignment, and to monitor the position of the beam on the COC, IO, and OUTPUT optics. Scattered 1064 nm light is collected by the camera’s lens. Video cameras are monochrome and are sensitive to visible and IR light. Lenses are selected for each camera to image the appropriate field of view.

4.3.1 Video Camera Characteristics

4.3.1.1 Video Camera Performance Characteristics

The specifications for the Sony XC-ST50 video camera, which is the proposed replacement for the XC-75 that was used for Initial LIGO, are shown in Table 5. The camera will be used without the internal IR filter.

The video camera is specified to have 525 TV lines vertical resolution and 570 TV lines horizontal resolution.

The sensitivity is specified to be 400 lx, with f/8 aperture stop—the minimum illumination is 0.3 lx, with f/1.4 aperture and without the internal IR filter.

The TV signal system is EIA Standard.

The video camera complies with the limits of a Class A digital device and meets the EN50081-2 emissions standard.

The video camera meets the requirements 3.3.1, 3.3.2, and 3.3.4. However, it may not meet the EMI requirement of 3.3.3.

4.3.1.2 Video Camera Physical Characteristics

The XC-ST50 is a small, lightweight one-piece camera. The camera body's measurements are 29 x 44 mm (same as the XC-75/73); however, the camera depth measures only 57.5 mm long, approximately 19% shorter than the XC-75/73 at 71mm. The camera weighs 110 grams, approximately 20% lighter than the XC-75/73 at 140 grams.

4.3.1.3 Video Camera Interface Definitions

4.3.1.3.1 Interfaces to other LIGO detector subsystems

4.3.1.3.1.1 Mechanical Interfaces

The video camera will mount inside the video imaging assembly (D970211-B Video Imaging Assembly ASC Alignment), as shown in Figure 20.

The camera mounting tube, item1, clamps to the outer diameter of the video camera viewport.

Table 5: Specification: Sony XC-ST50

Image Device	1/2" IT CCD
Effective Picture Elements	768 (H) x 494 (V)
Signal System	EIA Standard
Horizontal Frequency	15.734 kHz +/-1%
Vertical Frequency	59.94 Hz
Lens Mount	C Mount
Flange Back	17.526 mm
Sync system	Internal/ External (auto)
External Sync System	HD/ VD (2 ~ 5 Vp-p), VS
External Sync Frequency	Horizontal sync frequency +/-1%
Jitter	Less than +/-50 nsec
Scanning System	525 lines, 60 fields/s, 2:1 interlaced
Video Output	1.0 Vp-p, negative, 75 ohms unbalanced
Horizontal Resolution	570 TV lines
Sensitivity	400 lx, F8 (g compensation ON, 0 dB)
Minimum Illumination	0.3 lx (F1.4, AGC ON, without IR cut filter)
S/N Ratio	60 dB
Gain	AGC (0-18 dB) / Manual (0-18 dB) / Fixed (0 dB) Selectable
Gamma	On/OFF
Normal Shutter	1/100 ~ 1/10,000 s
External Trigger Shutter	1/4 ~ 1/10,000 s
Power Requirements	DC 12 V +/-10%
Power Consumption	2.0 W
Dimensions	44 (W) x 29 (H) x 57.5 (D) mm
Mass	110 g
Operation Temp./Mois.	-5°C ~ +45°C / 20 ~ 80%
Storage Temp./Mois.	-30°C ~ +60°C / 20 ~ 95%
Vibration	10 G (20 ~ 200 Hz)
Shock Resistance	70 G
MTBF	70,600 hrs.
Regulations	UL1492, FCC Class A Digital Device, CE (EN50081-2 + EN50082-2), AS4251.1 + AS4252.2

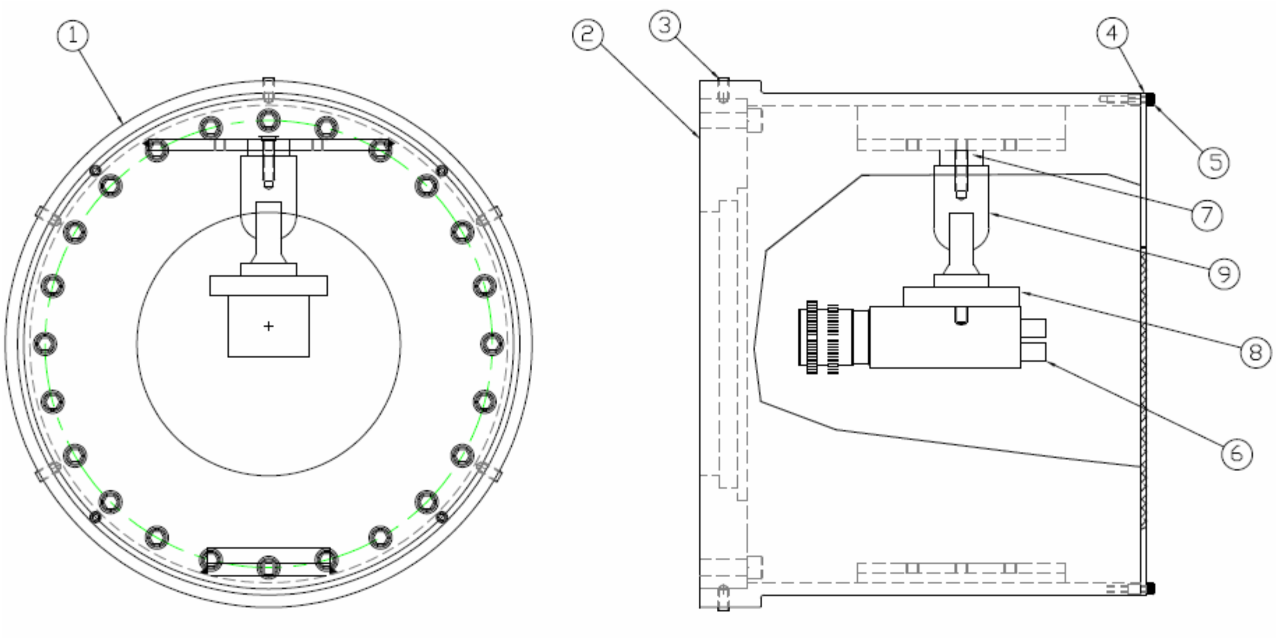

Figure 20: Video Imaging Assembly

4.3.1.3.1.2 Electrical Interfaces

CDS will provide regulated 12 VDC @ 0.2 A power for the video camera.

CDS will provide a 75 ohm coax video cable and a TV monitor for viewing the camera image.

4.3.1.4 Video Camera Reliability

4.3.1.4.1 Mean Time Before Failure

The MTBF is specified by the manufacturer to be 70600 hrs. The video camera meets the requirement 3.3.4.

4.3.1.4.2 Video Camera Maintainability

The video camera will be replaced before the specified MTBF.

4.3.1.4.3 Video Camera Environmental Conditions

4.3.1.4.3.1 Natural Environment

4.3.1.4.3.1.1 Temperature and Humidity

The video camera is designed to function with the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 6 Environmental Performance Characteristics

Operating	Non-operating (storage)	Transport

+20C to +25C, 20-70% RH, non- condensing	0C to +60C, 10-90% RH, non-condensing	0C to +60C, 10-90% RH, non- condensing

4.3.1.5 Transportability

All items will be transportable by commercial carrier without degradation in performance. As necessary, provisions shall be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation shall be utilized to prevent damage.

4.3.2 Design and Construction

4.3.2.1 Workmanship

The video camera is manufactured in accordance with standard commercial practices.

4.3.2.2 Interchangeability

All the same model number video cameras are interchangeable.

4.3.2.3 Safety

This item will meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements.

4.3.2.4 Human Engineering

Not applicable.

4.3.3 Assembly and Maintenance

The manufacturer's instruction manual will determine the maintenance requirements.

4.3.4 Documentation

The documentation will consist of the manufacturer's working drawings, assembly drawings, and instruction manual.

4.3.4.1 Specifications

The manufacturer's specifications will apply.

4.3.4.2 Design Documents

Revised drawings and calibration documents will be produced as necessary.

4.3.4.3 Engineering Drawings and Associated Lists

The video imaging assembly drawing used for Initial LIGO, D970211-B Video Imaging Assembly ASC Alignment will apply.

4.3.4.4 Technical Manuals and Procedures

The manufacturer's product manual will apply.

4.3.5 Logistics

The design will include a list of all recommended spare parts and special test equipment required.

4.3.6 Precedence

4.3.7 Qualification

4.4 Illumination

The edge outline and other fiducial features of the principal optical elements in the IFO will be highlighted by illumination from a flood lamp mounted to a chamber port.

4.4.1 Illumination Characteristics

4.4.1.1 Illumination Performance Characteristics

The illuminator lamp is an industrial 70 W industrial halogen flood unit, Waldmann HGWK-70-24 or equivalent. This lamp was used in Initial LIGO, and it provided satisfactory illumination for video camera viewing of the suspended optics. The illuminator lamp meets the requirement 3.4.1.

The EMI characteristics of the lamp are not listed. The illuminator lamp may not meet the requirement 3.4.2.

4.4.1.2 Illumination Physical Characteristics

A picture of the Waldmann HGWK-70-24 is shown in Figure 21.

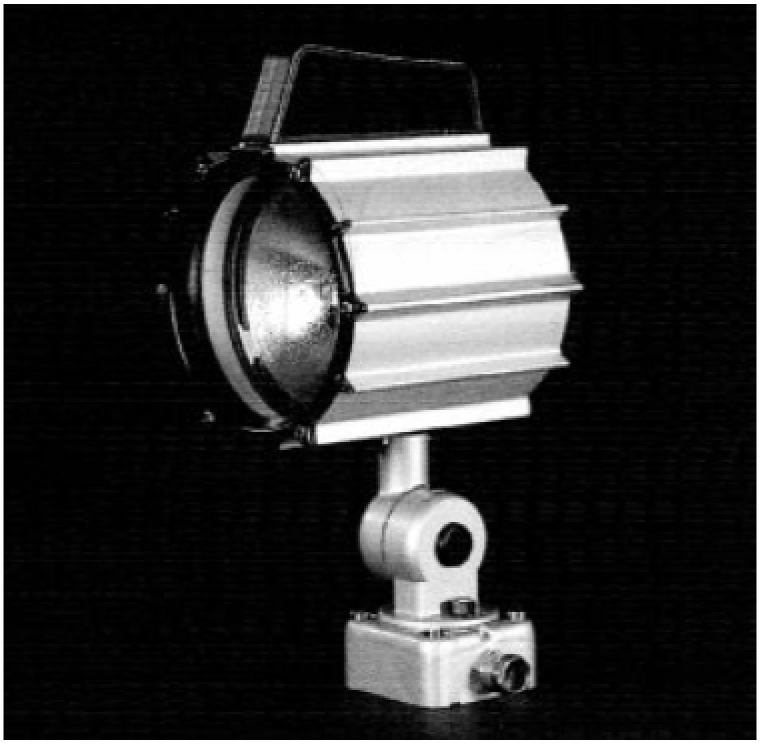

Figure 21: Waldmann HGWK-70-24V halogen flood lamp

4.4.1.3 Illumination Interface Definitions

4.4.1.3.1 Interfaces to other LIGO detector subsystems

4.4.1.3.1.1 Mechanical Interfaces

The illuminator lamp, item 6, will mount to the backing plate, item 5, which is mounted to the illuminator viewport via the illuminator mount, item 2, (D970212-B Illuminator Assembly ASC Alignment), as shown in Figure 22.

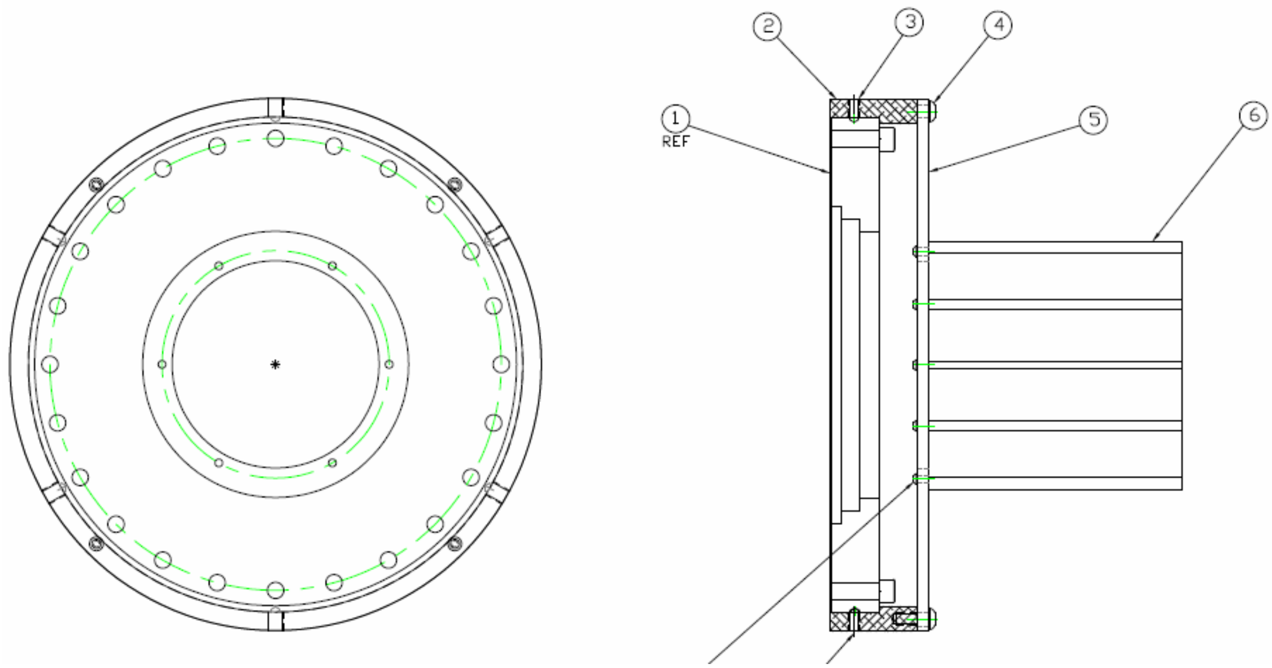

Figure 22: Illuminator assembly

4.4.1.3.1.2 Electrical Interfaces

CDS will provide 24 VDC @ 3 A electrical power. Each lamp will be turned on or off remotely.

4.4.1.4 Illuminator Reliability

4.4.1.4.1 Mean Time Before Failure

The lifetime of the lamp is specified to be 3500 hrs. This meets the requirement 3.4.3..

4.4.1.4.2 Maintainability

The illuminator lamp will be replaced before the specified MTBF.

4.4.1.4.3 Video Camera Environmental Conditions

4.4.1.4.3.1 Natural Environment

4.4.1.4.3.1.1 Temperature and Humidity

The illuminator is designed to function with the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 7 Environmental Performance Characteristics

Operating	Non-operating (storage)	Transport
+20C to +25C, 20-70% RH,	0C to +60C, 10-90% RH,	0C to +60C, 10-90% RH,

non- condensing	non-condensing	non- condensing

4.4.1.5 Transportability

All items shall be transportable by commercial carrier without degradation in performance. As necessary, provisions will be made for measuring and controlling environmental conditions (temperature and accelerations) during transport and handling. Special shipping containers, shipping and handling mechanical restraints, and shock isolation will be utilized to prevent damage. All containers will be movable by forklift.

4.4.2 Design and Construction

4.4.2.1 Workmanship

The illuminator is manufactured in accordance with standard commercial practices.

4.4.2.2 Interchangeability

All the illuminators are interchangeable.

4.4.2.3 Safety

This item shall meet all applicable NSF and other Federal safety regulations, plus those applicable State, Local and LIGO safety requirements. A hazard/risk analysis shall be conducted in accordance with guidelines set forth in M950046-F LIGO Project System Safety Management Plan, section 3.3.2.

4.4.2.4 Human Engineering

Not applicable.

4.4.3 Assembly and Maintenance

The manufacturer's instruction manual will determine the maintenance requirements.

4.4.4 Documentation

The documentation will consist of the manufacturer's working drawings, assembly drawings, and instruction manual.

4.4.4.1 Specifications

The manufacturer's specifications will apply.

4.4.4.2 Design Documents

Revised drawings and calibration documents will be produced as necessary.

4.4.4.3 Engineering Drawings and Associated Lists

The illumination assembly drawing used for Initial LIGO, D970212-B Illuminator Assembly ASC Alignment will apply.

4.4.4.4 Technical Manuals and Procedures

The manufacturer's technical manual will apply.

4.4.5 Logistics

The design will include a list of all recommended spare parts and special test equipment required.

4.4.6 Precedence

4.4.7 Qualification

5 Quality Assurance Provisions

This section includes all of the examinations and tests to be performed in order to ascertain the product, material or process to be developed or offered for acceptance conforms to the requirements in section 3.

5.1 General

5.1.1 Responsibility for Tests

AOS will conduct tests to verify the as-delivered performance specifications of the sub-system.

5.1.2 Special Tests

5.1.2.1 Engineering Tests

TBD

5.1.2.2 Reliability Testing

5.1.2.2.1 Optical Lever

Doug Cook is presently conducting reliability tests for the proposed optlev diode laser.

5.1.2.2.2 Video Camera

The reliability of the video cameras that will be used in ADLIGO was evaluated during Initial LIGO. Therefore, no further reliability testing will be conducted.

5.1.2.2.3 Viewports

The reliability of the viewports that will be used in ADLIGO was evaluated during Initial LIGO. Therefore, no further reliability testing will be conducted.

5.1.3 Configuration Management

Configuration control of specifications and designs shall be in accordance with the LIGO Detector Implementation Plan.

5.2 Quality conformance inspections

Design and performance requirements identified in this specification and referenced specifications shall be verified by inspection, analysis, demonstration, similarity, test or a combination thereof per the Verification Matrix, Appendix 1 (See example in Appendix). Verification method selection shall be specified by individual specifications, and documented by appropriate test and evaluation plans and procedures. Verification of compliance to the requirements of this and subsequent specifications may be accomplished by the following methods or combination of methods:

5.2.1 Inspections

Manufactured parts with LIGO identification numbers or marks will be inspected to determine conformity with the procurement specification.

A witness sample will be acceptable proof of the properties of anti-reflection coatings applied to viewports

5.2.2 Demonstration

A demonstration of the visual quality of the video camera image of the optics in the chamber will be acceptable as verification of the resolution characteristics of the video camera and the acceptable intensity level of the illumination lamp.

5.2.3 Test

The power of the optlev laser diode will be measured with a calibrated laser power meter to determine compliance with the manufacturer's specification.

The signal-to-noise ratio of the output signal from an assembled optlev receiver with a known input laser power will be measured to determine the acceptable performance of the QPD.

6 Preparation for Delivery

Packaging and marking of equipment for delivery will be in accordance with the Packaging and Marking procedures specified herein.

6.1 Preparation

- Vacuum preparation procedures as outlined in E960022-B LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures will be followed for all components intended for use in vacuum. After wrapping vacuum parts as specified in this document, an additional, protective outer wrapping and provisions for lifting shall be provided.
- Electronic components will be wrapped according to standard procedures for such parts.

6.2 Packaging

Procedures for packaging will ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection will be provided for shipping loads and environmental stress during transportation, hauling and storage. The shipping crates used for large items will use for guidance military specification MIL-C-104B, Crates, Wood; Lumber and Plywood Sheathed, Nailed and Bolted. Passive shock witness gauges will accompany the crates during all transits.

For the viewports, the shipping preparation will include double bagging with Ameristat 1.5TM plastic film (heat sealed seams as practical, with the exception of the inner bag, or tied off, or taped with care taken to insure that the tape does not touch the cleaned part). The bag will be purged with dry nitrogen before sealing.

6.3 Marking

Appropriate identification of the product, both on packages and shipping containers; all markings necessary for delivery and for storage, if applicable; all markings required by regulations, statutes, and common carriers; and all markings necessary for safety and safe delivery will be provided.

Identification of the material will be maintained through all manufacturing processes. Each component will be uniquely identified. The identification will enable the complete history of each component to be maintained (in association with Documentation “travelers”). A record for the optical lever support structures will indicate all weld repairs and fabrication abnormalities.

The specification for marking the viewports will state that marking fluids, die stamps and/or electro-etching is not permitted. A vibratory tool with a minimum tip radius of 0.005" is acceptable for marking on surfaces that are not hidden from view. Engraving and stamping are also permitted.

7 Notes

Appendix A Quality Conformance Inspections

Appendix A contains a table that lists the requirements and the method of testing requirements. TBD

Table 8 Quality Conformance Inspections

Paragraph	Title	I	A	D	S	T
	Performance Characteristics					
	Controls Performance					
	Timing Performance‘					