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AOS: PO Mirror Assembly & Telescope, and OMMT 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 PO Mirror Assembly and PO Telescope, and the Output Mode Matching Telescope (OMMT).

1 Introduction

1.1 Purpose

The purpose of this document is to derive the design requirements for Auxiliary Optics Support (AOS) system 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 PO Mirror Assembly and PO Telescope, and the Output Mode Matching Telescope (OMMT) subsystems.

1.2.1 PO Mirror Assembly and PO Telescope

This subsystem will generate optical pick-off (PO) beams from core optical elements and deliver those beams with a specified beam waist and location to the LSC/ASC system for gravity wave detection, feedback control of the interferometer (IFO) alignment and length, and for monitoring purposes. These PO beams include the following: BS PO, ITMx PO, ETMx transmitted beam, ETMy transmitted beam, and APS beam.

1.2.1.1 PO Mirror Assembly

The BS PO Mirror Assembly is comprised of a mirror and a double pendulum suspension for suspending the mirror from the optical table in the BSC chamber. The BS PO mirror will be pointed remotely in pitch and yaw.

The ITMx PO Mirror Assembly is comprised of three fixed mirrors that direct the ITMx PO beam into the aperture of the ITMX PO telescope.

1.2.1.2 PO Telescope

The BS PO telescope is comprised of the BS PO mirror, BSPOM1, and a second suspended mirror, BSPOM2, which together form an off-axis, spherical mirror, beam-reducing telescope. Various steering mirrors are used for directing the BS PO beam to the ISC detection bench.

The ITMx PO telescope is a non-suspended, off-axis parabolic mirror, beam-reducing telescope. It is a modification of the design used for Initial LIGO. Various steering mirrors are used for directing the BS PO beam to the ISC detection bench.

The ETM telescope is a refractive telescope. The identical telescopes that were used for Initial LIGO will be re-used for ADLIGO.

1.2.2 OMMT

The OMMT is identical to the IO MMT. It consists of a primary spherical mirror suspended in an LOS and a secondary spherical mirror suspended in an SOS, which together comprise an off-axis, beam-reducing telescope. A third mirror, suspended in an SOS, provides steering of the OMMT output beam to the ISC detection bench. The OMMT beam will be coupled into the OMC by means of an ISC mode-matching telescope that is not within the scope of this subsystem.

1.3 Definitions

1.4 Acronyms

AOS - Auxiliary Optics Support

APS - anti-symmetric port signal

AR - Antireflection mirror coating

ASC - Alignment Sensing and Control

BS - Beam Splitter

BSC - Beam Splitter Chamber

BSPOM – Beam splitter PO mirror

CDS – Computer Data Systems

COS - Core Optics Support

DLC – Dynamic Light Control

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

HAM - Horizontal Access Module

HR – Hi-reflectance mirror coating

IAS – Initial Alignment System

IFO - LIGO interferometer

IO - Input Optics

ISC- Interferometer Sensing and Control

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

LIGO - Laser Interferometer Gravity Wave Observatory

LOS – Large Optic Suspension

LSC - Length Sensing and Control

LVEA-vacuum equipment area

mm – millimeter

MMT – mode matching telescope

mrad – milliradian

MTBF – mean time before failure

NA – not applicable

nm – nanometer

OMC – Output Mode Cleaner

OMMT – output mode matching telescope

OPTLEV- optical lever

OSEM – sensor/actuator head

PO - Pick-off

p-p, peak to peak

ppm - parts per million

PRM – Power Recycling Mirror

p-v, peak to valley

Q – quality factor

QPD – quadrant photo diode

RH – relative humidity

rms - root-mean-square

rtHz – root Herz

SLC – Stray Light Control

SOS – Small Optic Suspension

SRD - Science Requirements Document

SRM – Signal Recycling Mirror

SW – Solid Works

TBD - To Be Determined

TCS – Thermal Compensation System

TRANSMON – ETM transmission monitor

urad – microradian

W - Watt

WFS – wave front sensor

1.5 Applicable Documents

1.5.1 LIGO Documents

1. T010076-01 Optical Layout for Advanced LIGO
2. T980007-00 PO Telescope Aberrations on Wavefront Sensor Performance
3. T980010-01 COS Preliminary Design
4. T960151-02 Large and Small Optics Suspension Electronics Design Requirements
5. E950111-A LIGO Naming Convention
6. M950046-F LIGO Project System Safety Management Plan
7. E960022-B LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
8. E000386-01 Tel_Par Primary Mirror, LIGO2
9. E000387-01 Tel_Par Secondary Mirror, LIGO2
10. T980104-00 COS Final Design
11. L970061-00-D Guidance for Seismic Component Cleaning, Baking, and Shipping Preparation
12. MIL-C-104B

1.5.2 Non-LIGO Documents

2 General description

2.1 Specification Tree

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

2.2 Product Perspective

2.2.1 PO Mirror Assembly and Telescope Perspective

2.2.1.1 BS PO Mirror and Telescope

The BS PO mirror, BSPOM1, is suspended from the optical table in BSC3 (in the non-folded IFO).

A second, suspended spherical mirror on HAM4, BSPOM2, together with BSPOM1 forms the BS PO Telescope.

Additional steering mirrors comprise the BS PO beam optical train.

2.2.1.2 ITMX PO Mirror and Telescope

The ITMX PO mirror is the first mirror, ITMxPOM1, of a horizontal and a vertical periscope that aligns the ITMx PO (BS AR1 ghost) beam into the entrance aperture of the ITMx PO telescope.

The ITMX PO telescope is of an off-axis parabolic mirror reflecting design that is mounted to the optical table in HAM4.

Additional steering mirrors comprise the ITMx PO beam optical train.

2.2.1.3 ETM Telescope

The ETM telescopes from Initial LIGO will be reused and suspended from the optical tables in the end chambers. An entrance baffle will be placed in front of the ETM telescope to vignette the ETM transmitted beam to the size of the clear aperture of the ETM telescope. The output beam from the ETM telescope will be attenuated by a variable attenuator and steered onto a suspended TRANSMON detection bench behind the ETM telescope.

Additional steering mirrors and beam splitters comprise the ETM output beam optical train.

2.2.1.4 OMMT

The OMMT is a three-mirror, beam reducing telescope with suspended, spherical mirrors, identical to the IO MMT.

Additional steering mirrors comprise the OMMT beam optical train.

2.3 Product Functions

2.3.1 PO Mirror Assembly and Telescope Functions

2.3.1.1 BS PO Mirror and BS PO Telescope

The function of the BS PO Mirror, BSPOM1, is to reflect the BSHR3 ghost beam to BSPOM1, which is the second mirror of the BS PO Telescope.

The function of the BS PO Telescope is to reduce the diameter of the BS PO Beam. The BS PO optical train then directs the BS PO beam to the ISC WFS on HAM6.

2.3.1.2 ITMX PO Mirror and ITMX PO Telescope

The BSAR1 ghost beam, which is the prompt reflection of the main IFO beam from the BS AR surface incident from the ITMx mirror direction, is reflected by the ITMx PO mirror, ITMxPOM1. The second mirror, ITMxPOM2, forms a horizontal periscope. The third mirror, ITMxPOM3, forms a vertical periscope that reflects the ITMx PO beam into the ITMx PO Telescope.

The function of the ITMx PO Telescope is to reduce the diameter of the ITMx PO Beam. The ITMx PO optical train then directs the ITMx PO beam to the ISC WFS.

2.3.1.3 ETM Telescope

The function of the ETM Telescope is to reduce the diameter of the beam transmitted through the ETM HR surface. It also serves the dual function of transmitting and receiving the Hartmann sensing beam for the ETM HR surface, which enters the output end of the telescope from outside the vacuum through a dichroic beam splitter.

2.3.1.3.1 ETM Baffle

A baffle is placed at the entrance to the ETM telescope to vignette the beam to the input aperture size.

2.3.1.4 TRANSMON Power Attenuator

The output beam from the ETM telescope is attenuated by an adjustable power attenuator, which reflects unwanted power into a beam dump. The attenuated beam is directed subsequently to the TRANSMON detection system, which is mounted to the suspended optical table that supports the ETM telescope.

2.3.1.5 OMMT

The function of the OMMT is to reduce the diameter of the output beam from the SRM (APS beam) and to steer the beam into the aperture of the Output Faraday Isolator.

2.4 General Constraints

2.4.1 PO Mirror Assembly and Telescope Constraints

The clear aperture of the PO mirrors and the entrance apertures of the corresponding PO telescopes will be the same as the 100 ppm diameter of the main interferometer beam, which is 258 mm.

The entrance aperture of the Initial LIGO ETM telescope is 160 mm.

The output beam diameters from the telescopes will be < 20 mm, measured at the 100 ppm intensity level. This is the same as Initial LIGO. See T980010-01 COS Preliminary Design.

2.5 Assumptions and Dependencies

2.5.1 Interferometer Design Parameters

The ETM beam attenuator design is based on the following assumed parameters:

Arm cavity power	800000 W
IFO Gaussian beam radius, w	60 mm
Transmissivity of ETM HR	0.000015
ETM transmitted power	12 W

2.5.2 Recycling Cavity Degeneracy

The locations and the beam sizes for the PO Mirrors and PO telescopes are based on the assumption that the recycling cavities are degenerate, similar to the Initial LIGO design.

2.5.3 Size of ETM TRANSMON beam

The output beam diameter from the ETM telescope is approximately 19.5 mm, measured at the 100 ppm intensity level. This is the same as Initial LIGO.

2.5.4 CDS Interface Characteristics

CDS will provide in-vacuum voltages and data cables for controlling the PO mirror and telescope suspensions, for remotely controlling steering mirrors, and for controlling the TRANSMON attenuator.

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 BS PO Mirror System Requirements

3.1.1 Clear Aperture

The input clear aperture for the BSPOM1 shall be > 100 ppm intensity diameter of the main beam, which is assumed to be equal to 258mm. This requirement is taken from Initial LIGO.

The clear input apertures OF the optical elements in the BS PO train shall not cause vignetting of the BS PO beam.

3.1.2 Stay Clear Distance from Main IFO Beam

The BS PO Mirror shall stay clear of the 100 ppm intensity edge of the main beam, which is assumed to have a radius of 129 mm from the main beam centerline. A minimum separation of 30mm is desirable (see T010076-01 Optical Layout for Advanced LIGO).

3.1.3 Pointing Accuracy

3.1.3.1 Coarse Pointing

The gross angular alignment of the suspended BS PO mirrors will be within 2 mrad of the desired orientation by using fixtures during installation. The pitch and yaw motion of the BS PO mirror shall be adjustable within the suspension structure to provide +/- 2 mrad angular pointing range during installation.

3.1.3.2 Fine Pointing

The BSPOM1 mirror will be steered to place the BS PO beam at the center of the BSPOM2 mirror. BSPOM2 mirror is steered to place the BS PO beam at the center of the final optical element of the BS PO train. The suspended BS PO mirrors shall be pointed remotely with sufficient pitch and yaw precision to ensure that the BS PO beam is not vignetted by more than 10% at the final element of the optical train.

3.1.3.3 Damping

The PO Mirror suspension shall provide damping with a Q < 10 (TBD) for pitch, yaw, longitudinal, and transverse motions.

3.1.4 Wavefront Distortion of BS PO Mirror Optical Train

The total wavefront distortion in the optical train shall be < 0.9 waves in order to maintain the WFS signal contrast ratio >5:1; see T980007-00 PO Telescope Aberrations on Wavefront Sensor Performance. This requirement is derived in T980010-01 COS Preliminary Design.

3.2 ITMx PO Telescope Requirements

3.2.1 Clear Aperture

The clear input aperture for the ITMx POM1 shall be > 100 ppm intensity profile diameter of the main beam, which is assumed to be equal to 258mm diameter. This requirement is taken from Initial LIGO.

The clear input apertures for the optical elements in the ITMx PO train shall not cause vignetting of the ITMx PO beam.

3.2.2 Stay Clear Distance from Main IFO Beam

The ITMx PO Mirror shall stay clear of the 100 ppm intensity edge of the main beam, which is assumed to have a radius of 129 mm from the main beam centerline. A minimum separation of 30mm is desirable (see T010076-01 Optical Layout for Advanced LIGO).

3.2.3 Field of View

The ITMx PO telescopes shall provide an angular field-of-view of +/- 0.0004 rad to allow for beam shifts and other misalignment errors during the interferometer pump-down. This requirement is derived in T980010-01 COS Preliminary Design.

3.2.4 Wavefront Distortion

The total wavefront distortion in the optical train shall be < 0.9 waves in order to maintain the WFS signal contrast ratio >5:1; see T980007-00 PO Telescope Aberrations on Wavefront Sensor Performance. This requirement is derived in T980010-01 COS Preliminary Design.

3.2.5 Pointing Accuracy of ITMx PO Beam

In order to avoid vignetting of the ITMx PO beam at the last element of the optical train, the pitch and yaw pointing of the output ITMx PO beam shall be adjustable via a remotely controlled steering mirror to a precision of +/- 0.10 mrad.

3.3 ETM Telescope

The requirements will be the same as Initial LIGO (see T980104-00 COS Final Design). The ETM telescopes from Initial LIGO will be re-used for ADLIGO.

3.3.1 Clear Aperture

The input clear aperture is 156 mm diameter. This is the as-built value of Initial LIGO.

3.3.2 Input Baffle

An input baffle with 156 mm diameter aperture shall be placed at the entrance to the ETM telescope coaxial with the telescope's principal axis.

3.3.3 Spot Centroid at TRANSMON QPD

The output of the ETM telescope will be focused onto the TRANSMON QPD and provide a relative measurement of the pointing direction of the beam transmitted through the ETM.

The focused spot on the TRANSMON QPD shall provide an unambiguous determination of the centroid of the focused spot.

3.3.4 TRANSMON Power Attenuation

The optical power incident on the TRANSMON QPD shall be varied remotely in logarithmic steps over a power range of a factor 100.

3.3.5 Pointing Accuracy

3.3.5.1 Coarse Pointing

The gross angular alignment of the ETM telescope during installation will be within 2 mrad of the desired orientation.

The pitch and yaw motion of the ETM telescope shall be adjustable by the suspension structure to provide +/- 2 mrad angular pointing range during installation.

3.3.5.2 Fine Pointing

The focus lens of the TRANSMON QPD is located approximately 400 mm beyond the output of the ETM telescope. In order to ensure that the output beam is not vignetted by more than 10%, the maximum allowed beam deflection at that location will be 2mm.

The angular orientation of the installed ETM telescope shall be adjustable remotely to a precision of < +/- 630 urad.

3.3.5.3 Damping

The ETM telescope suspension shall provide damping with a Q < 10 (TBD) for pitch, yaw, longitudinal, and transverse motions.

3.4 OMMT

3.4.1 Clear Aperture

The clear aperture of the OMMT mirror, OMMT1, shall be the same as the input mode matching telescope mirror MMT3, which is approximately 285 mm diameter. The APS beam shall pass through the OMMT optical train without further vignetting.

3.4.2 Wavefront Distortion

In order to maximize the mode coupling into the OMC, the maximum wavefront distortion of the OMMT optical train shall be < 0.5 waves @ 1064 nm.

3.4.3 Pointing Accuracy

3.4.3.1 OMMT1

3.4.3.1.1 Coarse Pointing

The gross angular alignment of the suspended OMMT mirrors using fixtures during installation will be within 0.5 mrad of the desired orientation. The pitch and yaw motions of OMMT mirrors shall be adjustable by the suspension to provide +/- 0.5 mrad angular pointing range during installation.

3.4.3.1.2 Fine Pointing

OMMT2 mirror is located approximately 15500 mm beyond OMMT1, and it is desired to center the beam on OMMT2 within 1 mm. Therefore, the angular orientation of OMMT1 shall be adjusted remotely with a pointing precision of < 65 urad.

3.4.3.2 OMMT2

3.4.3.2.1 Coarse Pointing

See 3.4.3.1.1.

3.4.3.2.2 Fine Pointing

OMMT3 mirror is located approximately 16600 mm beyond OMMT2, and it is desired to center the beam on OMMT3 within 1 mm. Therefore, the angular orientation of OMMT2 shall be adjusted remotely with a pointing precision of < 60 urad.

3.4.3.3 OMMT3

3.4.3.3.1 Coarse Pointing

See 3.4.3.1.1.

3.4.3.3.2 Fine Pointing

The OMC is located approximately 4250 mm beyond OMMT2, and it is desired to center the beam on OMMT2 within 1 mm. Therefore, the angular orientation of OMMT3 shall be adjusted remotely with a pointing precision of < 235 urad

3.4.4 Damping

The OMMT mirror suspensions shall provide damping with a Q < 10 for pitch, yaw, longitudinal, and transverse motions.

3.4.5 Surface Quality

The micro-roughness of the OMMT mirror surfaces shall be < 0.8 Angstrom rms in order to minimize surface scattering.

The optical transmissivity of the APS path shall be maximized with the use of ion-beam dielectric high reflectance and antireflection coatings.

4 Conceptual Design

4.1 BS PO Mirror and Telescope

4.1.1 BS PO Mirror Characteristics

The suspended BS PO mirror, BSPOM1, is also the primary mirror of the BS PO telescope. The secondary mirror of the BS PO telescope is the suspended, spherical mirror, BSPOM2.

4.1.1.1 BS PO Mirror and Telescope Performance Characteristics

4.1.1.1.1 Clear Aperture

The diameter of the BSPOM1 is 282 mm, with a 2.5 mm bevel around the circumference. Allowing for a 5 mm clamp around the edges of the mirror, the clear aperture is 267 mm. This meets the requirement 3.1.1.

The diameter of the BS PO beam is reduced by the factor 15, from 258 mm to 17.2 mm, at BSPOM2. The diameter of BSPOM2 is 75 mm. This meets the requirement 3.1.1.

All subsequent steering mirrors have a clear aperture of 50/1.4 = 36 mm. This meets the requirement 3.1.1.

4.1.1.1.2 Stay Clear Distance from Main IFO Beam

The separation between the BS PO beam centerline and the main beam centerline at the location of the BSPOM1 is 340 mm. The BSPOM1 bezel extends downward from the center of the BS PO beam by 153 mm. This provides a clear distance of 58 mm between the bottom of the BSPOM1 and the top edge of the main beam at the 100 ppm diameter. This meets the requirement 3.1.2.

4.1.1.1.3 Pointing Accuracy

4.1.1.1.3.1 Coarse Pointing

The BSPOM1 suspension will be designed to have an internal adjustment range of +/- 2 mrad in pitch and yaw orientation.

The SOS suspension for BSPOM2 has a pitch and yaw range of 28 mrad p-p (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements).

These meet the requirement 3.1.3.1.

4.1.1.1.3.2 Fine Pointing

The fine pointing of the BS PO beam will be accomplished in two stages. 1) BSPOM1 will be pointed so as to direct the BS PO beam onto the center of the BSPOM2 within 10% of the beam diameter, a distance 8390 mm away. This requires a pointing angle precision of 2/8390 = 240 urad. 2) BSPM2 will be pointed so as to direct the BS PO beam onto the center of the BS PO WFS aperture at the ISC detection bench, a distance 20562 mm away. This requires a pointing angle precision of 2/20562 = 97 urad.

The BSPOM1 suspension will be designed to have a +/- 50 urad pointing precision in pitch and yaw.

The SOS suspension for BSPOM2 has a pitch and yaw sensor noise of < 1.5 nanoradians / rtHz (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements). Assuming a 1 Hz bandwidth, this will provide << 50 urad pointing precision in pitch and yaw.

These meet the requirement 3.1.3.2.

4.1.1.1.3.3 Damping

The BSPOM1 and BSPOM2 suspensions will be designed to provide damping with a Q < 10 (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements) for pitch, yaw, longitudinal, and transverse motions. This meets the requirement 3.1.3.3.

4.1.1.1.4 Wavefront Distortion of BS PO Mirror and Telescope Optical Train

The off-axis angle spherical mirrors of the BSPOM1/BSPOM2 beam reducing telescope with spherical mirrors cause negligible astigmatic distortion of the wavefront, because the off-axis angles are small. The majority of the distortion is due to the specified 0.125 waves of surface distortion @ 0.633 nm wavelength (0.074 waves @ 1064 nm) on each of the two mirrors. The total distortion was calculated using ZEMAX. The ray-trace model of the BS PO telescope is shown in Figure 1. Zernike polynomials were used to place a total distortion of 0.074 waves @ 1064 nm on each of the three mirror surfaces, equally divided between spherical aberration, coma, and astigmatism. The total wavefront distortion of the BS PO telescope is < 0.35 waves p-v @ 1064 nm, as shown in Figure 2**.**

Additional distortion arises from the surfaces in the optical train. Assume there are 12 additional surfaces in the optical train of the BS PO WFS. Each surface will be specified to be < 0.1 wave distortion @ 633 nm wavelength. The total distortion will be < 0.40 waves @ 1064 nm wavelength. This meets the requirement 3.1.4.

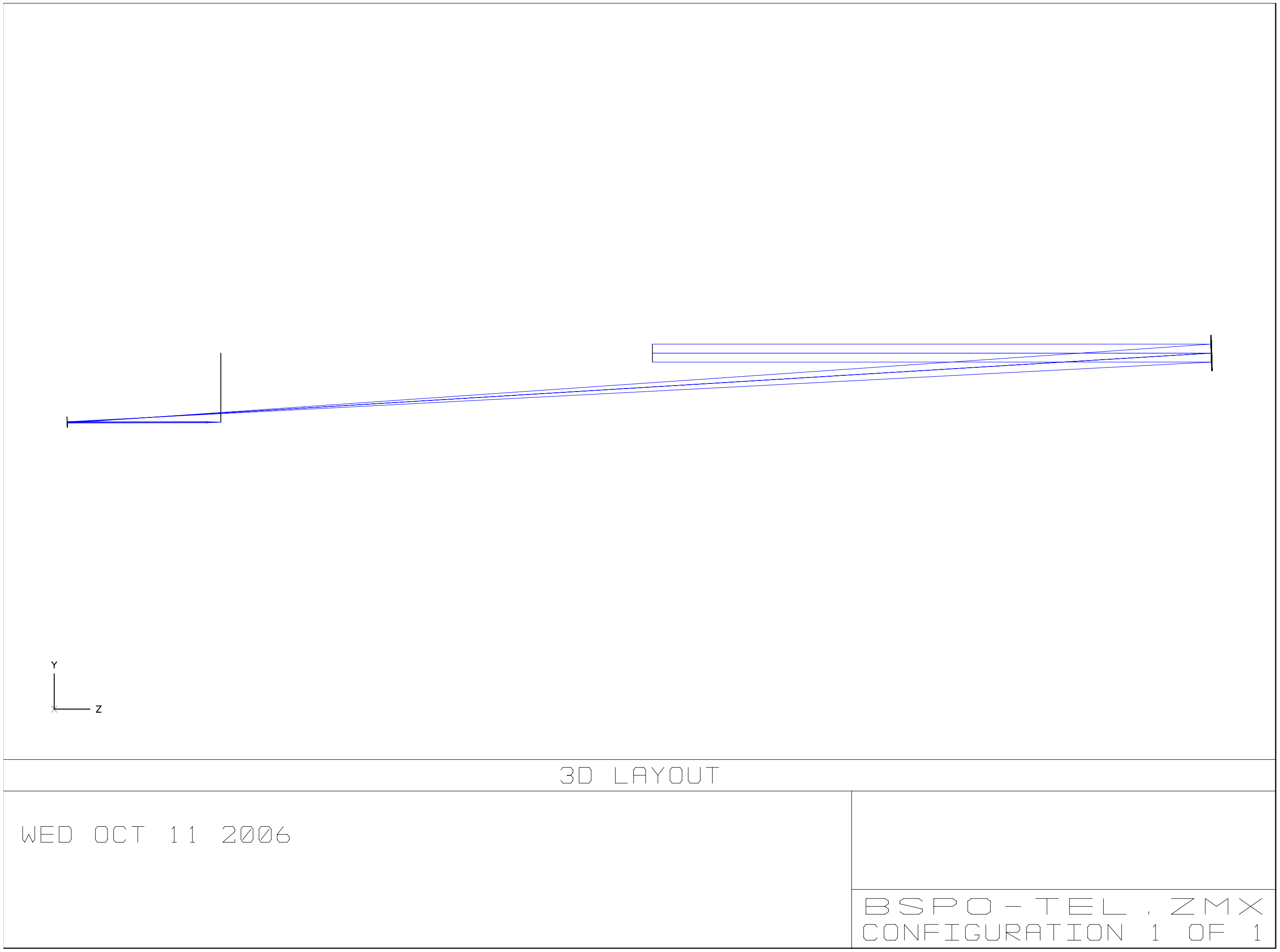

Figure 1: BSPO Telescope, ray model

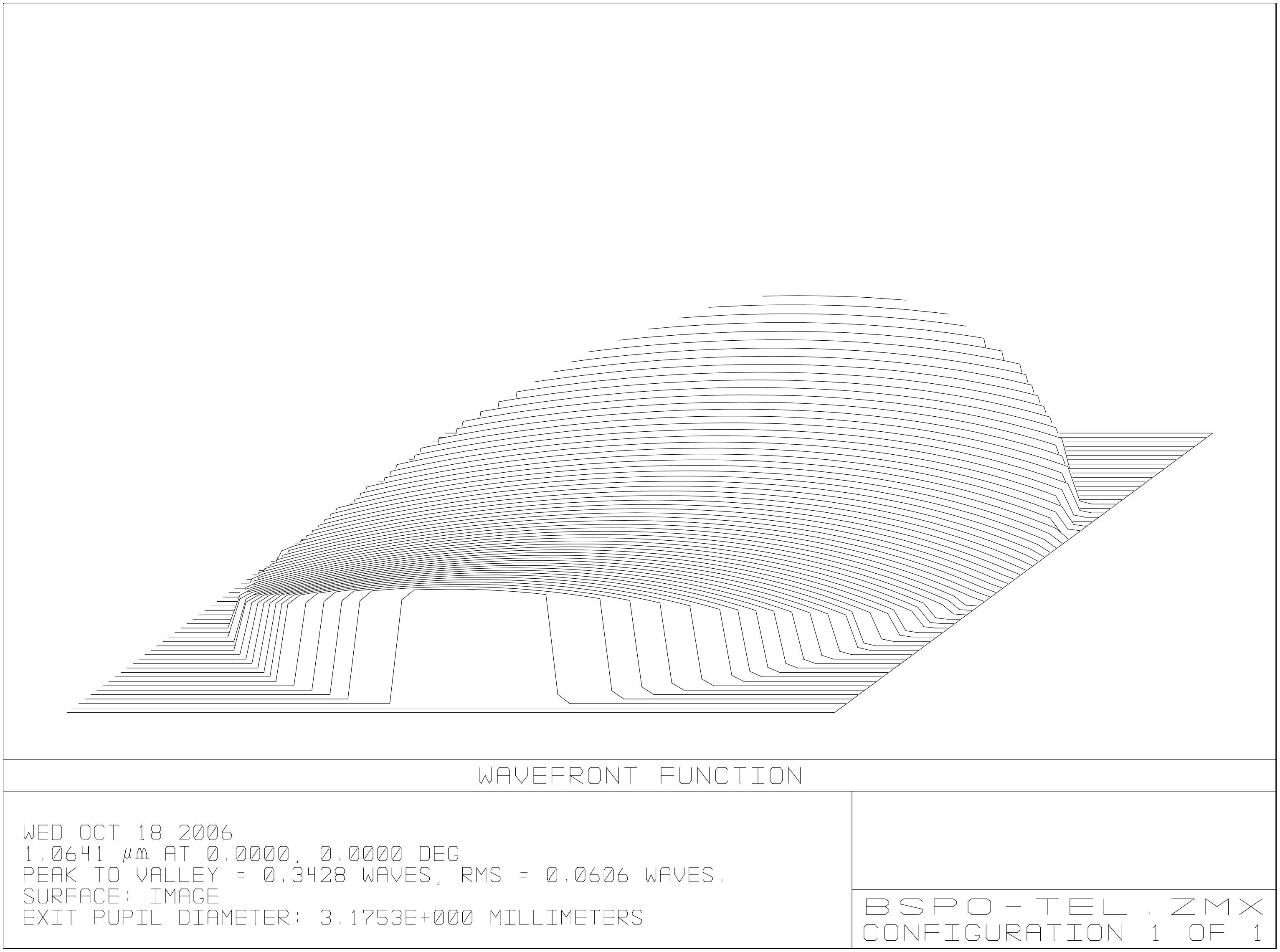

Figure 2: BSPO Telescope, wavefront aberration

4.1.1.2 BS PO Mirror and Telescope Physical Characteristics

4.1.1.2.1 BSPOM1

BSPOM1 is a spherical mirror. It is hung from a double pendulum suspension that is mounted in front of the ITMy SUS in BSC3, for the non-folded IFO. The earthquake stops and catching fixture will be mounted to the BSC walls. A SW model of the suspended BSPOM1 is shown in Figure 3.

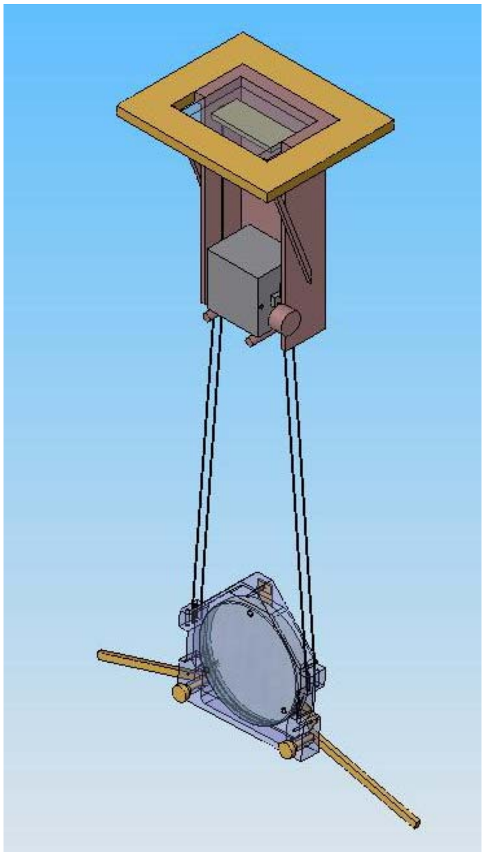

Figure 3: BS PO Mirror, BSPOM1 with suspension

BSPOM1 Characteristics

Radius of curvature	15262.3 mm
Outside diameter	282 mm
Clear Aperture	267 mm
Thickness	38 mm

4.1.1.2.2 BSPOM2

BSPOM2 is located on HAM4, for the non-folded IFO, and is suspended by an SOS, as shown in Figure 4. The optimum separation between the BSPOM1 and BSPOM2 mirror surfaces is 8193.4 mm.

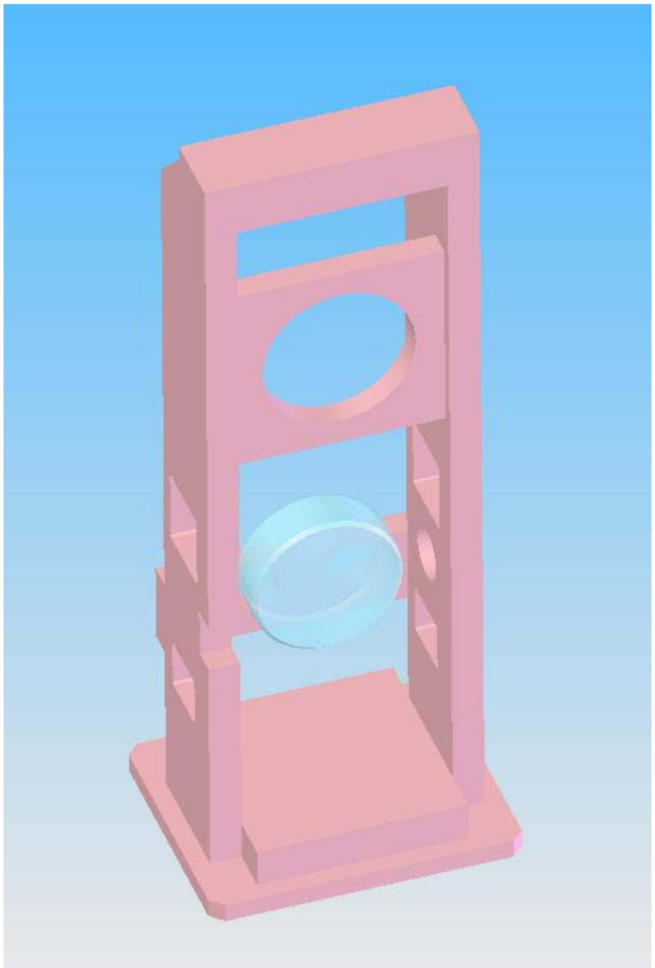

Figure 4: SOS Assembly

BSPOM2 Characteristics

Radius of curvature	1147.5 mm
Outside diameter	75 mm
Clear Aperture	70 mm
Thickness	25 mm

4.1.1.2.3 Electrical characteristics

4.1.1.2.3.1 BSPOM1 Suspension

CDS will provide appropriate (TBD) electrical currents for the OSEM to control the pitch and yaw angles of the BSPOM1 mirror.

4.1.1.2.3.2 BSPOM2 Suspension

CDS will provide appropriate (TBD) electrical currents for the OSEM to control the pitch and yaw angles of the BSPOM2 mirror.

4.1.1.3 BS PO Mirror Interface Definitions

4.1.1.3.1 Interfaces to other LIGO detector subsystems

4.1.1.3.1.1 Mechanical Interfaces

The BSPOM1 suspension will be clamped to the optical table in BSC3, for the non-folded IFO. The BSPOM2 SOS will be clamped to the optical table in HAM4, for the non-folded IFO.

4.1.1.3.1.2 Electrical Interfaces

The control currents for the BSPOM1 and BSPOM2 suspensions will enter the vacuum chambers through appropriate electrical feed-through (TBD), and will be connected to the suspension by means of appropriate electrical cables and connectors (TBD).

4.1.1.3.1.3 Optical Interfaces

BSPOM1 will intercept the BSHR3 ghost beam while maintaining the stay clear distance described in 4.1.1.1.2

4.1.1.3.1.4 Stay Clear Zones

See 4.1.1.1.2.

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 BS PO Mirror Reliability

4.1.1.4.1 Mean Time Before Failure

TBD

4.1.1.4.2 BS PO Mirror Maintainability

The following components are susceptible to failure:

1) OSEM

2) Suspension wires

If either of these components fails, the suspension assembly will be removed from the vacuum chamber and repaired. The physical location of the suspension will be preserved by means of alignment fixtures. The pointing angle of the mirrors will be reproduced by means of the optical lever associated with the particular suspended mirror.

4.1.1.4.3 BS PO Mirror Environmental Conditions

4.1.1.4.3.1 Natural Environment

4.1.1.4.3.1.1 Temperature and Humidity

The BS PO Mirrors are designed to operate in the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 1 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 BS PO Mirrors will function under normal atmospheric pressure conditions

4.1.1.4.3.1.3 Seismic Disturbance

The BS PO Mirrors will be mounted to isolated optical tables within the vacuum chambers and will not be subjected substantially to the ground seismic disturbances.

4.1.1.4.3.2 Induced Environment

4.1.1.4.3.2.1 Electromagnetic Radiation

NA

4.1.1.4.3.2.2 Acoustic

NA

4.1.1.4.3.2.3 Mechanical Vibration

NA

4.1.1.5 BS PO Mirror 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.

4.2 ITMx PO Telescope

4.2.1 ITMx PO Telescope Characteristics

The ITMX PO beam is the BSAR1 ghost beam that lies below the main signal recycling beam, as shown in Figure 5—this beam is the prompt reflection of the main IFO beam from the BS AR surface incident from the ITMx mirror direction. The BSAR1 ghost beam is extracted and reflected horizontally by ITMxPOM1. ITMxPOM2 and ITMxPOM3 form a vertical periscope that directs

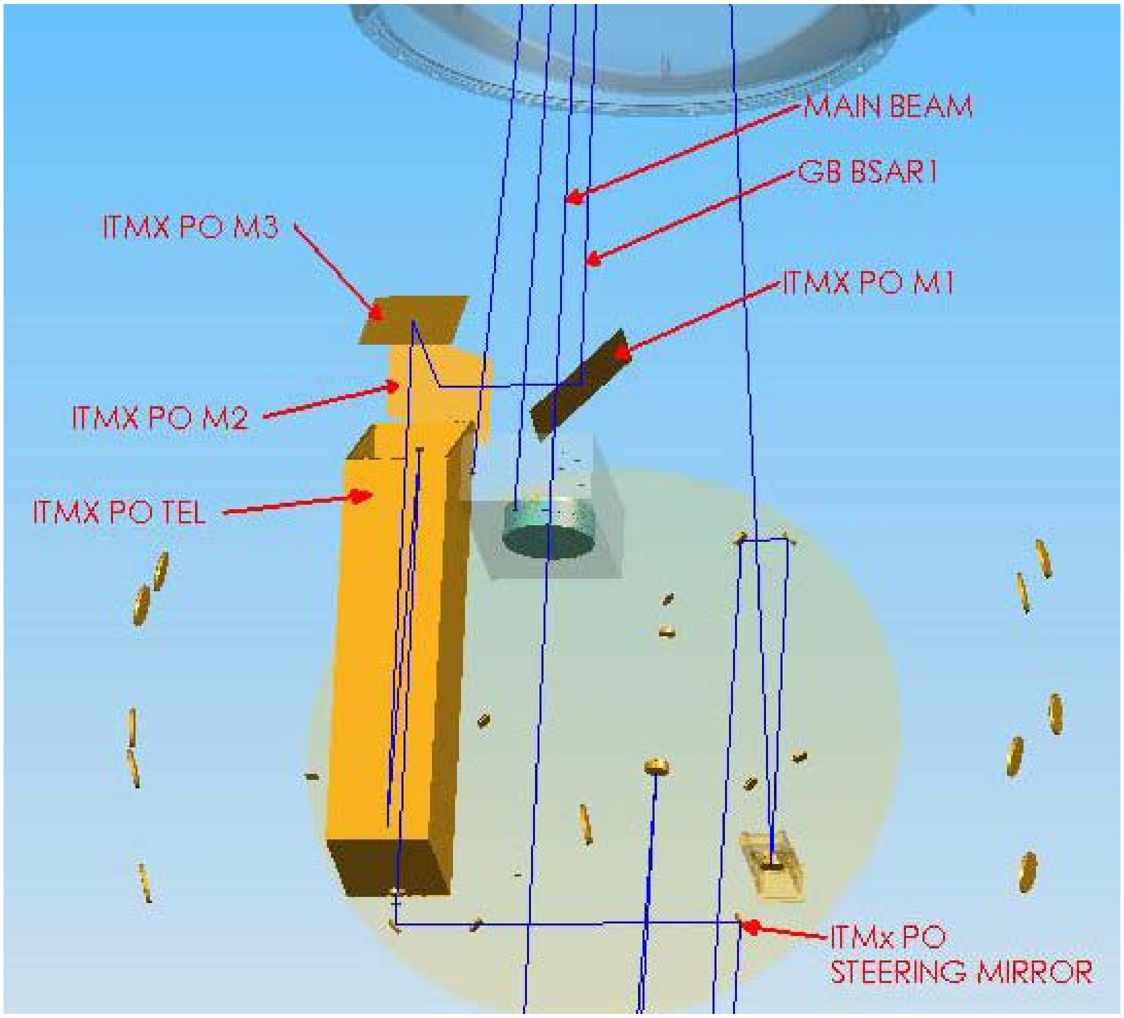

Figure 5: ITMx PO Telescope optical train

the ITMx PO beam into the ITMx PO Telescope, which sits on the optical table in HAM4, for the non-folded IFO.

The output ITMx PO beam is steered remotely by the ITMx PO steering mirror.

4.2.1.1 ITMx PO Telescope Performance Characteristics

4.2.1.1.1 Clear Aperture

4.2.1.1.1.1 ITMx PO Mirror

The upper edge of the ITMxPOM1 must be shortened by 14 mm to avoid vignetting the main IFO (APS) beam directly above it. The clear aperture of ITMxPOM1 will be 244 mm x 258 mm--although this is smaller than the requirement 3.2.1, the loss of power due to the missing 14 mm segment of the ITMx PO beam at the 100 ppm edge is negligible, and should be an acceptable exception.

4.2.1.1.1.2 ITMx PO Telescope

The diameter of the ITMx PO Telescope primary mirror is 300 mm, with a 20 mm unpolished border, leaving a clear aperture of 260 mm. This meets the requirement 3.2.1.

The 258 mm diameter PO beam will pass through the ITMx PO Telescope without vignetting. This meets the requirement 3.2.1.

The ITMx PO telescope has a demagnification ratio of 13.3; therefore, the output beam diameter at the 100 ppm intensity diameter is 19.4 mm, the same as Initial LIGO.

All subsequent steering mirrors have a clear aperture of approximately 50/1.4 = 36 mm. This meets the requirement 3.2.1.

4.2.1.1.2 Stay Clear Distance from Main IFO Beam

The upper edge of ITMxPOM1 is tangent to the 100 ppm lower boundary of the main beam. Therefore, the stay clear distance is zero. This meets the requirement 3.2.2.

4.2.1.1.3 Field of View

The ITM PO telescope has an angular field-of-view of +/- 0.0004 rad. See 4.2.1.1.4.1.

This meets the requirement 3.2.3.

4.2.1.1.4 Wavefront Distortion of ITMx PO Optical Train

4.2.1.1.4.1 ITMx PO Telescope

The off-axis parabolic mirrors of the ITM PO telescope cause negligible astigmatic distortion of the wavefront. The majority of the distortion is due to the specified 0.125 waves of surface distortion @ 0.633 nm wavelength (0.074 waves @ 1064 nm) on each of the two mirrors. The total distortion was calculated using ZEMAX. The ray-trace model of the ITM PO telescope is shown in Figure 6. Zernike polynomials were used to place a total distortion of 0.074 waves @ 1064 nm on each of the mirror surfaces, equally divided between spherical aberration, coma, and astigmatism. The total wavefront distortion of the ITMx PO telescope is < 0.15 waves p-v @ 1064 nm, as shown in Figure 7.

4.2.1.1.4.2 ITMx PO Mirrors

The ITM PO mirror surface deformation will be specified < 0.25 waves p-v @ 633 nm.

4.2.1.1.4.3 Steering Mirrors

The 2 in steering mirror deformation will be specified < 0.1 waves p-v @ 633 nm.

4.2.1.1.4.4 Total Wavefront Distortion of ITMx PO Telescope Optical Train

The additional surfaces of the optical train will add wavefront distortion. Assuming that the optical train of the ITM PO WFS is comprised of 6, 2 in steering mirror surfaces; 3, ITM PO mirror surfaces; 2 off-axis parabolic mirror surfaces; and a partridge in a pear tree; the total distortion @ 1064 nm wavelength will be < 0.31 waves. This meets the requirement 3.2.4.

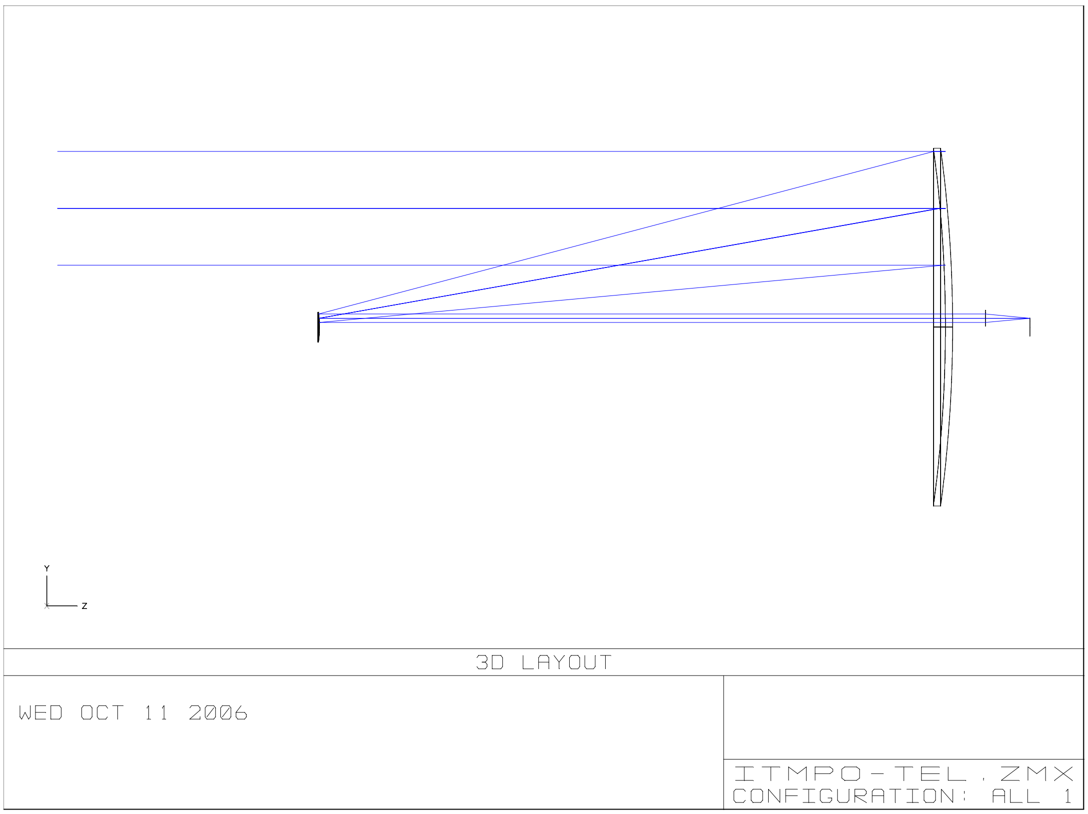

Figure 6: ITMx PO Telescope ray model

4.2.1.1.5 ITMx Steering Mirror

The ITMx steering mirror shown in Figure 5 will be the same as is used in the 40 M IFO. It consists of a PSH 5/2 SG-V PZT tilt platform with a 2 in mirror, mounted to a DLC mount. A schematic drawing is shown in Figure 8. The tilt platform has a range of +/- 2 mrad, with a pointing precision of 1 urad.

This meets the requirement 3.2.5.

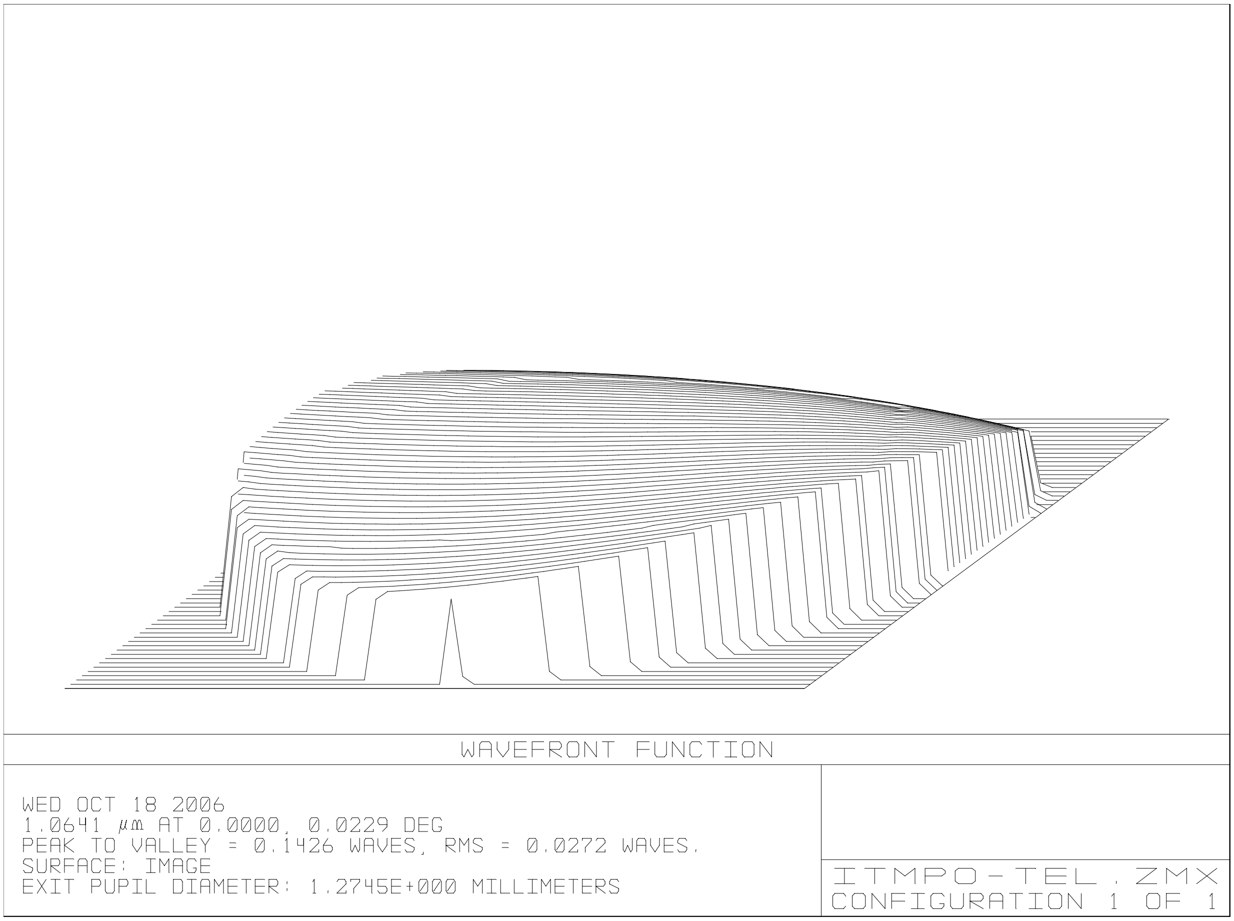

Figure 7: ITMx PO Telescope, wavefront distortion @ 0.4 mrad field angle

4.2.1.2 ITMx PO Telescope Physical Characteristics

4.2.1.2.1 ITMx PO Telescope

The concept for the off-axis parabolic ITMx PO Telescope is shown in Figure 9. This is a scaled-up version of the PO telescopes that were used for Initial LIGO.

The telescope is pre-focused at infinite conjugates before installation.

The specifications for the off-axis parabolic mirrors are given in E000386-01 Tel_Par Primary Mirror, LIGO2; and in E000387-01 Tel_Par Secondary Mirror, LIGO2.

4.2.1.2.2 Gimbaled Mount

The PO telescope is supported in the vicinity of the primary mirror by a fixed height gimbaled mount. The height of the input beam will be set by adjusting the height of the ITMxPOM3. The gimbaled mount allows the telescope body to pivot about the center of the primary mirror and point in the pitch and yaw angular directions during installation. The front mount is adjusted vertically to control the pitch angle, and is moved horizontally to control the yaw angle.

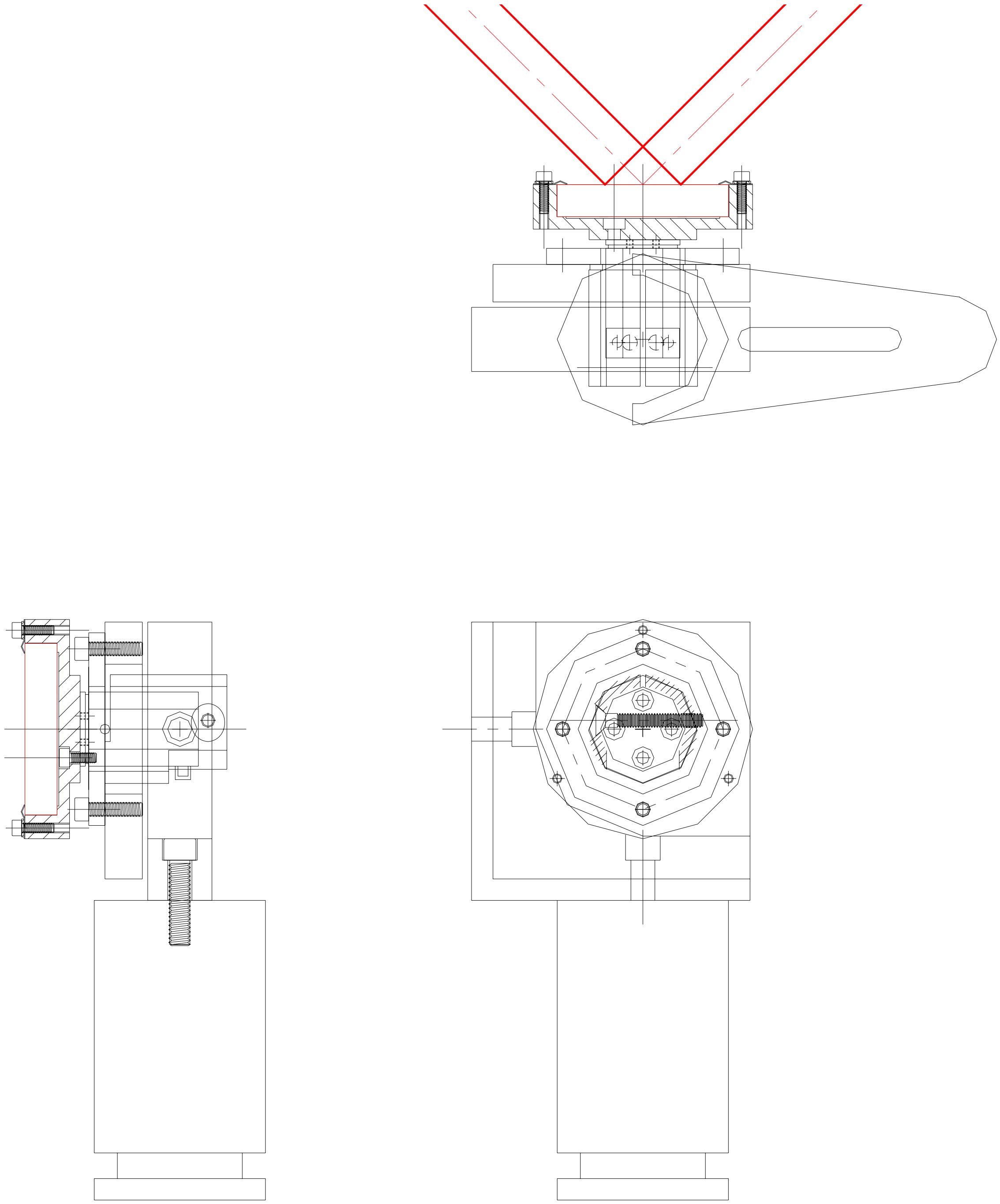

Figure 8: PZT steering mirror

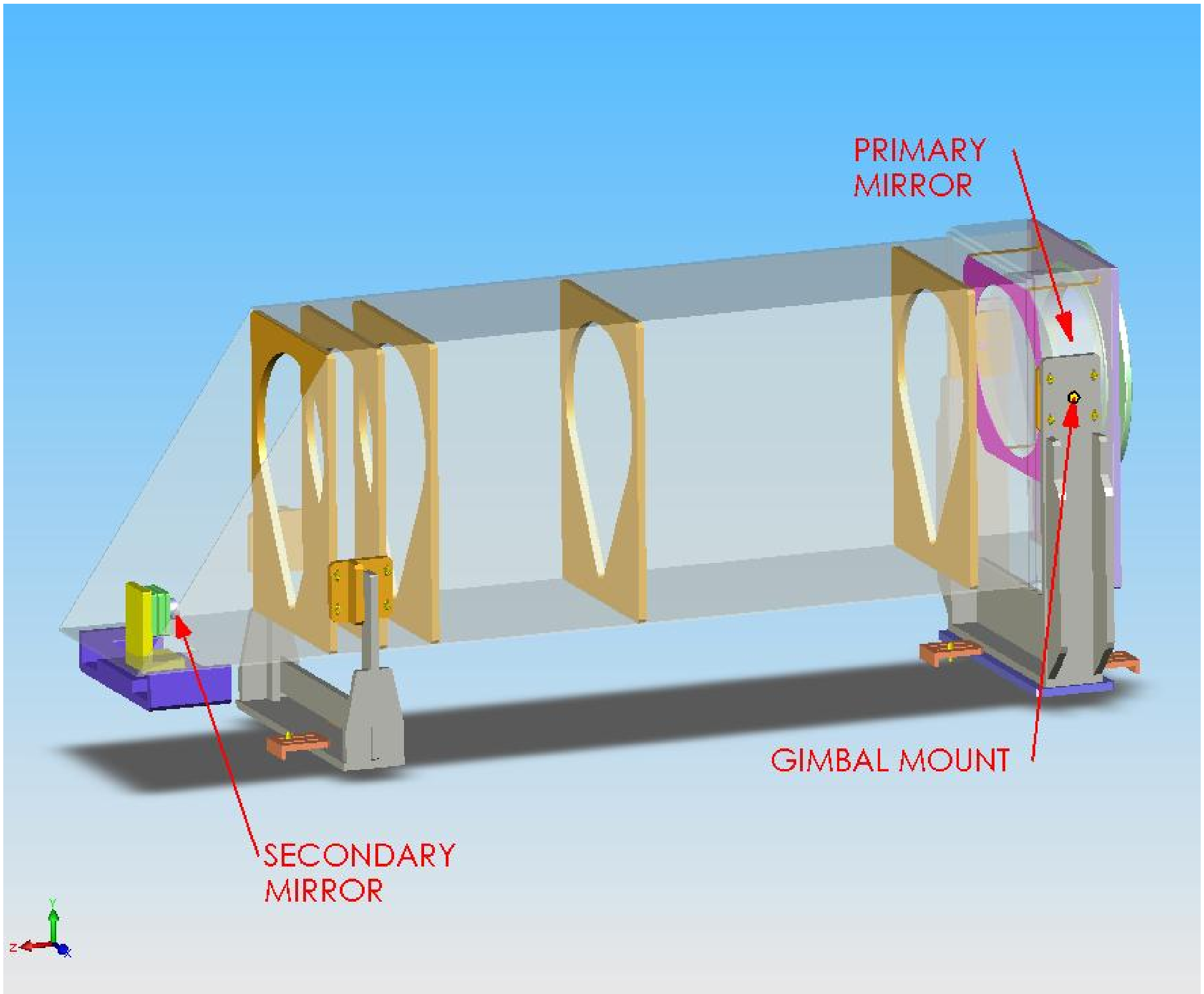

Figure 9: ITMx PO Telescope

4.2.1.2.3 Electrical characteristics

4.2.1.2.3.1 ITMx PO Telescope

NA

4.2.1.2.3.2 ITMx PO Remote Steering Mirror

CDS will provide appropriate (TBD) high voltage signals to control the pitch and yaw angles of the PZT Steering Mirror.

4.2.1.3 ITMx PO Telescope Interface Definitions

4.2.1.3.1 Interfaces to other LIGO detector subsystems

4.2.1.3.1.1 Mechanical Interfaces

The ITMx PO Telescope will be mounted to the optical table in HAM4, for the non-folded IFO.

4.2.1.3.1.2 Electrical Interfaces

The electrical control signals for the remote ITMx PO beam steering mirror will enter the vacuum chamber through an appropriate electrical feed-through (TBD), and will be connected to the mirror by means of an appropriate electrical cable and connector (TBD).

4.2.1.3.1.3 Optical Interfaces

ITMx PO Telescope will intercept the BSAR1 ghost beam while maintaining the stay clear distance described in 4.1.1.1.2.

4.2.1.3.1.4 Stay Clear Zones

See 4.1.1.1.2.

4.2.1.3.2 Interfaces external to LIGO detector subsystems

4.2.1.3.2.1 Mechanical Interfaces

4.2.1.3.2.2 Electrical Interfaces

4.2.1.3.2.3 Stay Clear Zones

4.2.1.4 ITMx PO Telescope Reliability

4.2.1.4.1 Mean Time Before Failure

4.2.1.4.1.1 ITMx PO Telescope

The experience with Initial LIGO is that the installed ITMx PO Telescope is expected to have a MTBF equal to the life of the project.

4.2.1.4.1.2 ITMx PO Remote Steering Mirror

TBD

4.2.1.4.2 ITMx PO Telescope Maintainability

The ITMx PO Telescope will not require maintenance.

The PZT element of the ITMx PO Steering Mirror is susceptible to failure:

If this component fails, the ITMx PO Steering Mirror assembly will be removed from the vacuum chamber and repaired. The physical location of the mirror will be retained by means of alignment fixtures. The pointing angle of the mirror will be recovered through realignment.

4.2.1.4.3 ITMx PO Telescope Environmental Conditions

4.2.1.4.3.1 Natural Environment

4.2.1.4.3.1.1 Temperature and Humidity

The ITMx PO Telescope and associated optical train 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

4.2.1.4.3.1.2 Atmospheric Pressure

The ITMx PO Telescope and associated optical train will function under normal atmospheric pressure conditions

4.2.1.4.3.1.3 Seismic Disturbance

The ITMx PO Telescope and associated optical train will be mounted to isolated optical tables within the vacuum chambers and will not be subjected substantially to the ground seismic disturbances.

4.2.1.4.3.2 Induced Environment

4.2.1.4.3.2.1 Electromagnetic Radiation

NA

4.2.1.4.3.2.2 Acoustic

NA

4.2.1.4.3.2.3 Mechanical Vibration

NA

4.2.1.5 ITMx PO Telescope 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.

4.3 ETM Telescope

The ETM telescopes from Initial LIGO will be re-used for ADLIGO.

The ETM Telescope assembly is shown in Figure 10. The ETM Telescope collects the beam that transmits through the HR surface of the ETM mirror. It will be mounted to an optical table that is suspended by a double pendulum suspension from the overhead optics table in the end BSC. The output beam from the telescope passes through an adjustable, power attenuating filter wheel, which reflects unwanted power into a beam dump. The attenuated beam will be directed to the TRANSMON detection system, which is mounted to the same optical table that supports the telescope. The TRANSMON detection components will be specified and provided by ISC.

The ETM Telescope has a dual function. The Hartmann sensing beam for the ETM HR surface enters the telescope output beam path through a dichroic beam splitter, is expanded by the telescope, reflects from the ETM HR surface and passes back out through the telescope and out through a vacuum viewport to the Hartmann wavefront sensor located outside the vacuum chamber.

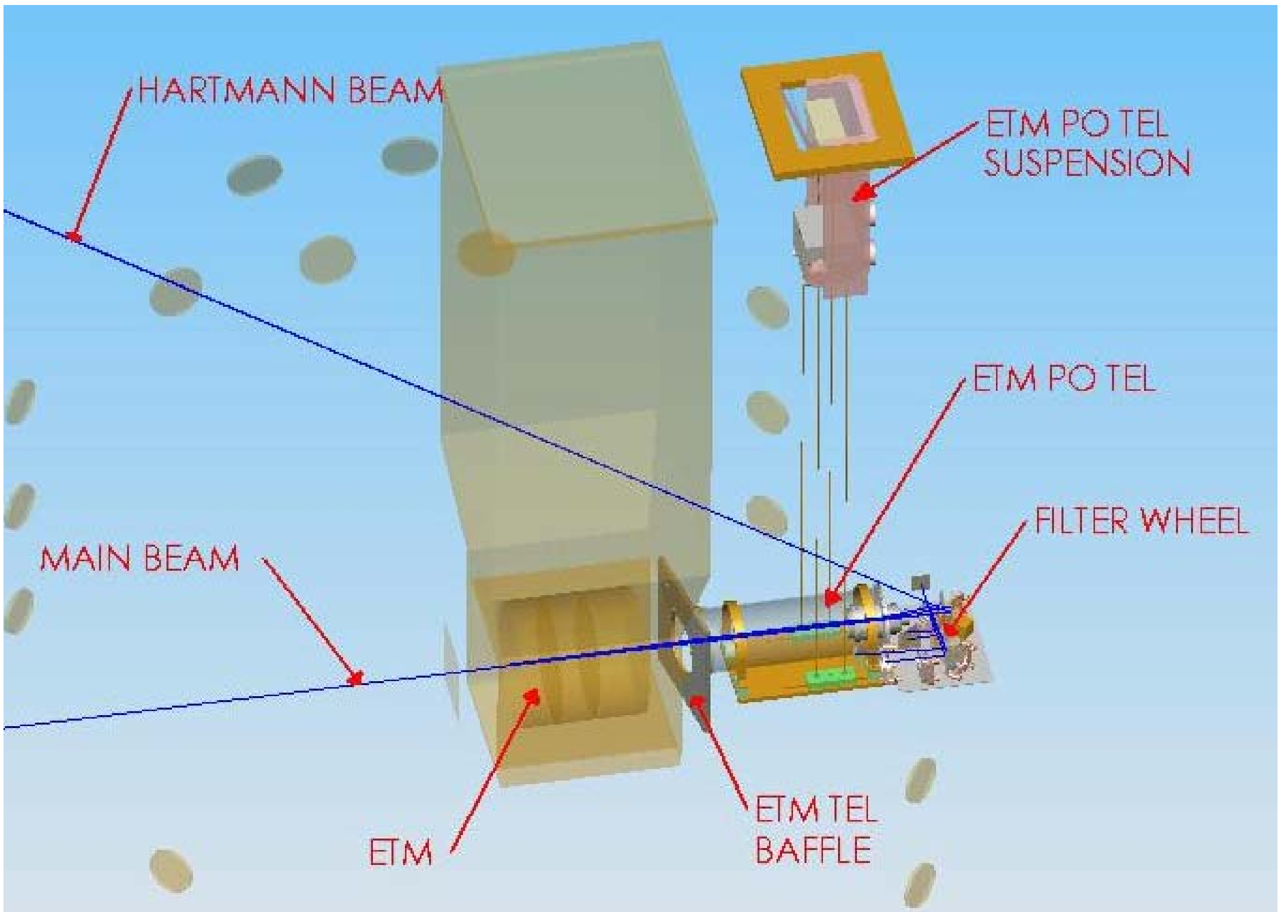

Figure 10: ETM Telescope assembly

4.3.1 ETM Telescope Characteristics

4.3.1.1 ETM Telescope Performance Characteristics

4.3.1.1.1 Clear Aperture

The entrance aperture of the ETM Telescope is 156 mm. The diameter of the BS PO beam is reduced through the telescope by a factor 8, from 156 mm to 19.5 mm. All subsequent steering mirrors and beam splitters have a clear aperture of approximately 50/1.4 = 36 mm.

4.3.1.1.2 Input Baffle

An absorbing baffle, shown in Figure 10, with diameter 156 mm and inclined at 10 degrees to the optical axis will be placed in front of the ETM Telescope to reduce the diameter of the transmitted ETM beam to match the clear aperture diameter of the ETM telescope. This meets the requirement 3.3.2.

The fraction of the transmitted beam through the ETM that will be rejected by the baffle is 0.034. Assuming that the transmitted beam power is 12 W, the baffle will reject 0.014 W.

4.3.1.1.3 Pointing Accuracy

4.3.1.1.3.1 Coarse Pointing

The ETM Telescope suspension will have an internal adjustment range of +/- 2 mrad in pitch and yaw orientation. This meets the requirement 3.3.5.1.

4.3.1.1.3.2 Fine Pointing

The ETM Telescope suspension will provide a +/- 50 urad pointing precision in pitch and yaw. This meets the requirement 3.3.5.2.

4.3.1.1.3.3 Damping

The ETM Telescope suspension mechanism will provide damping with a $Q < 10$ (TBD) for pitch, yaw, longitudinal, and transverse motions. This meets the requirement 3.3.5.3.

4.3.1.1.4 Field of View

The ETM telescope has an angular field-of-view of +/- 630 urad. See 3.3.5.2.

4.3.1.1.5 Spot Centroid at TRANSMON QPD

The ray model of the ETM Telescope is shown in Figure 11. A paraxial focus lens with a 100 mm focal length was placed at the output to simulate the TRANSMON focus lens and QPD.

The spot shape at the QPD was analyzed using ZEMAX physical optics propagation. The input Gaussian beam with a 60mm waist radius is incident on the telescope at the maximum field angle of 630 urad. The spot cross section perpendicular to the plane of incidence shows minimal distortion, as seen in Figure 12. The spot cross section in the plane of incidence exhibits an asymmetric ring pattern because of field curvature, as seen in Figure 13; however, the location of

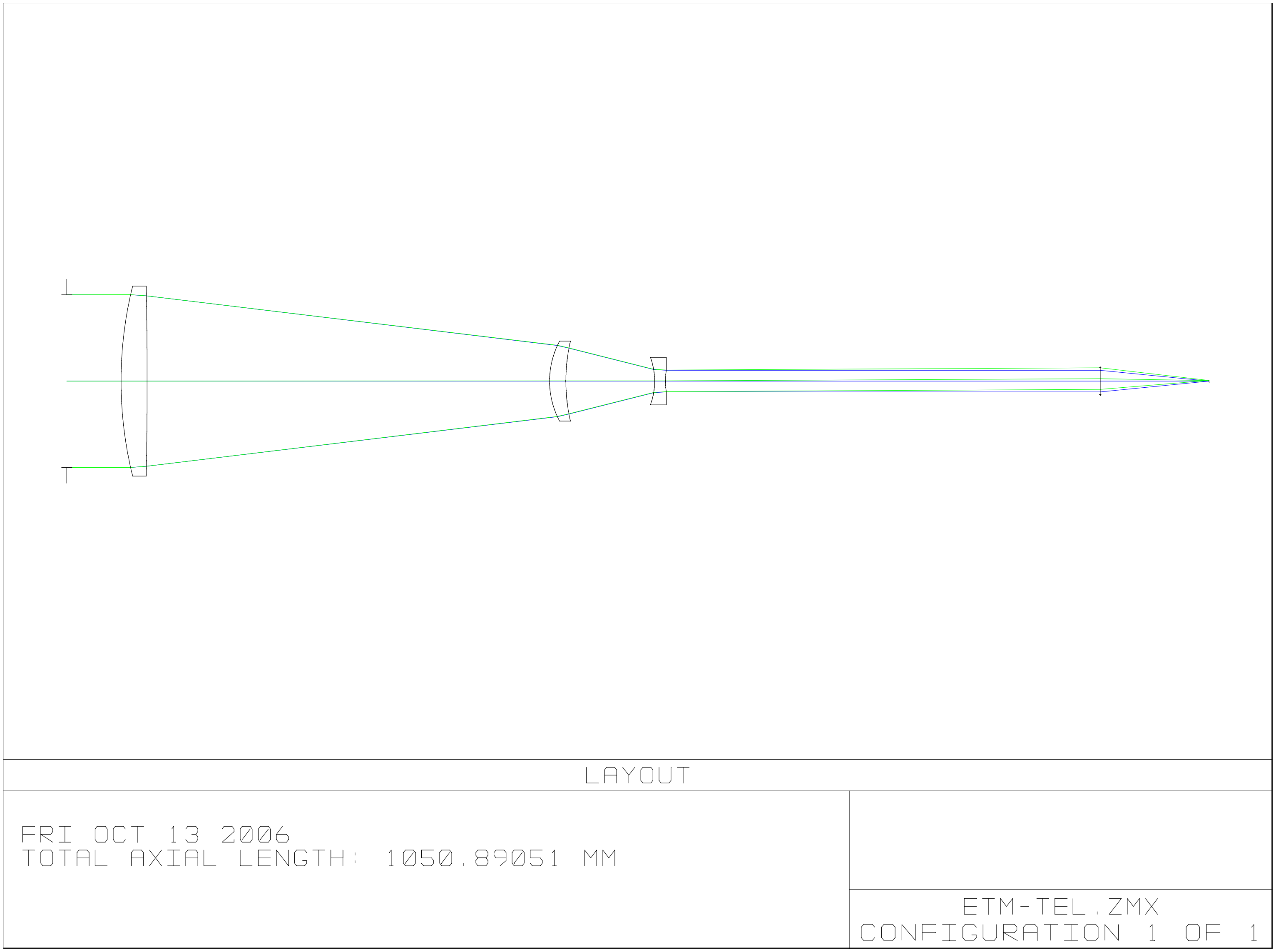

Figure 11: ETM Telescope, ray model

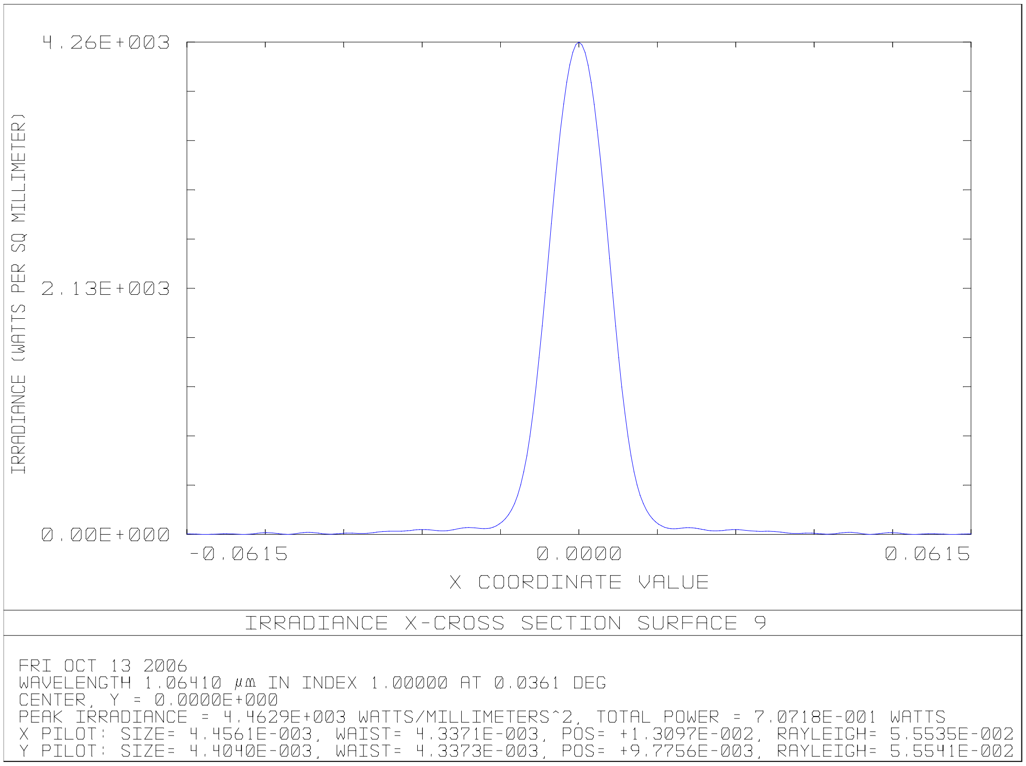

Figure 12: TRANSMON QPD spot, x-cross section

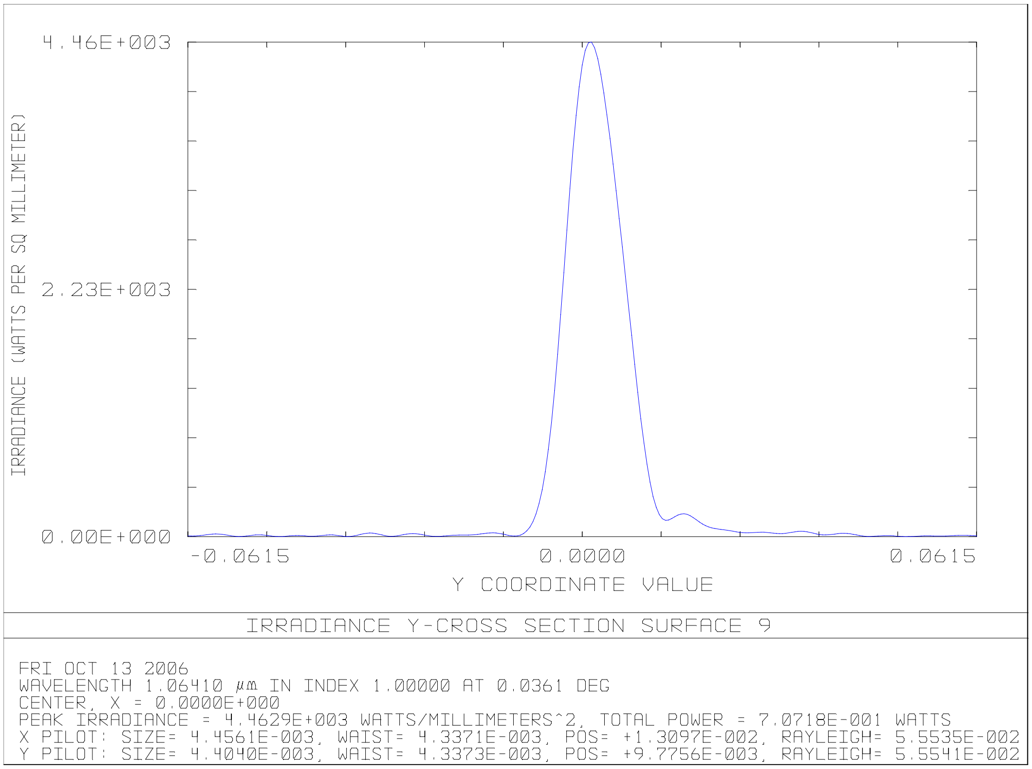

Figure 13: TRANSMON QPD spot, y-cross section

the spot centroid is unambiguous and will be adequate for determining the pointing direction of the ETM output beam. This meets the requirement 3.3.3.

4.3.1.2 Output Beam Attenuation

A concept for the attenuator wheel is shown in Figure 14. A variable attenuator, consisting of a rotating filter wheel with a series of beam splitters arranged radially around the filter wheel will attenuate the output beam from the ETM telescope and provide a safe power level for the TRANSMON QPD. The reflected power is dissipated in a beam dump.

The stepper motor is vacuum qualified.

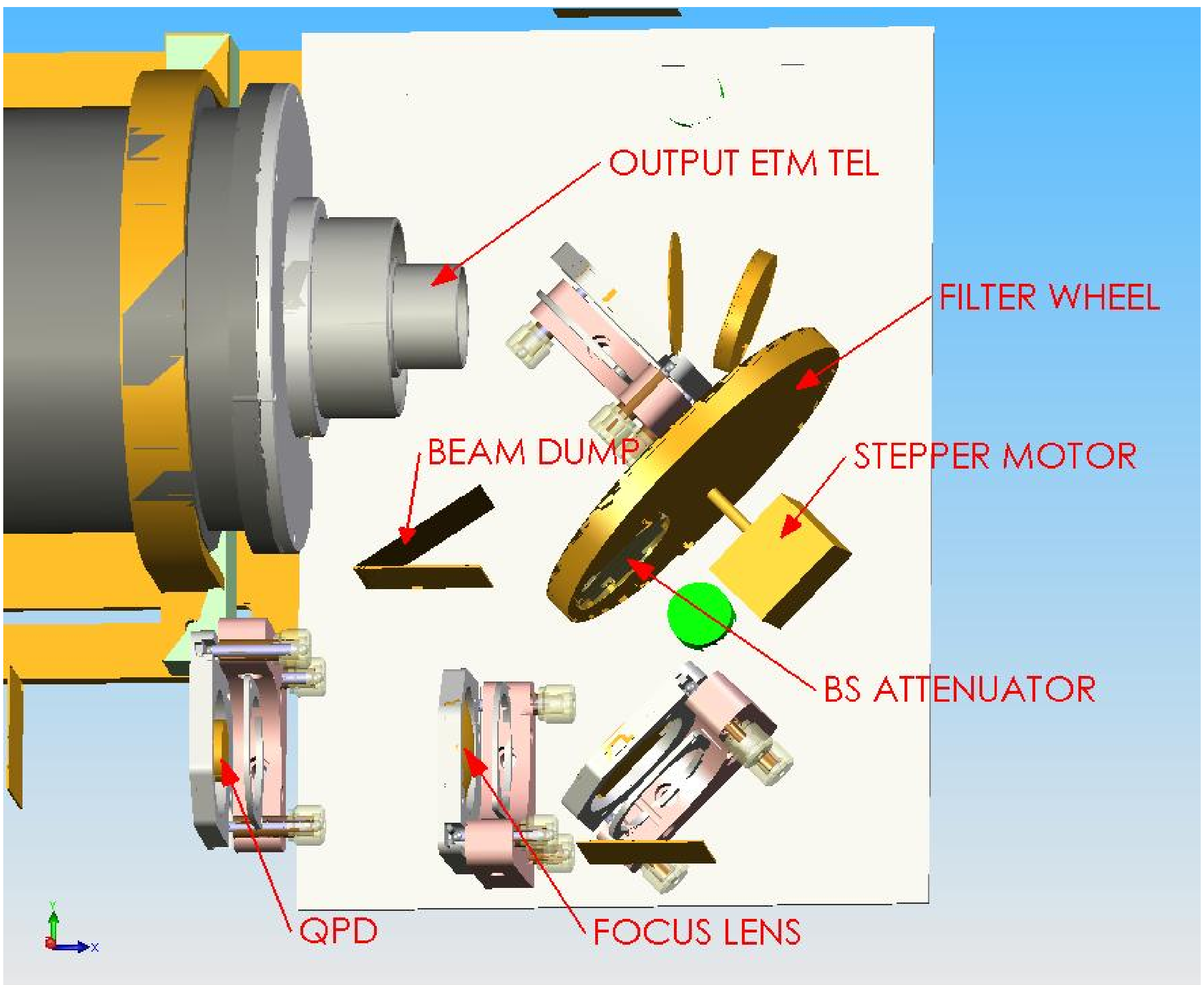

Figure 14: ETM beam attenuator

The attenuator will provide a factor 100 attenuation in logarithmic steps, as described conceptually in Table 3 TRANSMON attenuation factors.

Table 3 TRANSMON attenuation factors

ETM power, W	12.5	3.95	1.25	0.395	0.125
Attenuator transmissivity	0.01	.032	0.10	0.32	1.0
Dumped power, W	12.4	3.83	1.13	0.270	0
QPD power, W	0.125	0.125	0.125	0.125	0.125

4.3.1.3 ETM Telescope Physical Characteristics

The ETM Telescope assembly is shown in Figure 10. It consists of 1) ETM Telescope, 2) Input Baffle, 3) double pendulum suspension with platform for mounting the telescope, 4) Output Attenuator assembly, 5) and the Hartmann beam optics. The TRANSMON detection components will be specified and provided by ISC.

Weight of the suspended payload	9.5 kg
Height of the ETM Telescope axis below the optics table	1744 mm
Input clear aperture	158 mm
Demagnification ratio	8
Output clear aperture	19.5 mm

4.3.1.3.1 Electrical characteristics

4.3.1.3.1.1 ETM Telescope Suspension

CDS will provide appropriate (TBD) OSEM electrical currents to control the pitch and yaw angles of the telescope suspension.

4.3.1.3.1.2 ETM Beam Attenuator

CDS will provide appropriate stepper motor voltages to rotate the filter wheel (TBD).

4.3.1.4 ETM Telescope Interface Definitions

4.3.1.4.1 Interfaces to other LIGO detector subsystems

4.3.1.4.1.1 Mechanical Interfaces

The ETMx Telescope suspension will be clamped to the optical table in BSC9, for the non-folded IFO. The ETMy Telescope suspension will be clamped to the optical table in BSC10, for the non-folded IFO.

4.3.1.4.1.2 Electrical Interfaces

The control currents and voltages for the ETM Telescope suspensions and for the stepper motor will enter the vacuum chambers through an appropriate electrical feed-through (TBD), and will be connected to the suspension by means of appropriate electrical cables and connectors (TBD).

4.3.1.4.1.3 Optical Interfaces

The optical axis of the ETM Telescope will be collinear with the centerline of the transmitted ETM beam.

4.3.1.4.1.4 Stay Clear Zones

The ETMx Telescope suspension will stay clear of the clamping area of the ETM quad SUS structure on the BSC optics table.

4.3.1.4.2 Interfaces external to LIGO detector subsystems

4.3.1.4.2.1 Mechanical Interfaces

4.3.1.4.2.2 Electrical Interfaces

4.3.1.4.2.3 Stay Clear Zones

4.3.1.5 ETM Telescope Reliability

4.3.1.5.1 Mean Time Before Failure

The ETM Telescope has been used since the installation of Initial LIGO, and it is anticipated that it has an MTBF equal to the lifetime of the project.

The ETM Telescope suspension is a new design based upon similar designs in Initial LIGO and in the GEO IFO. The MTBF is TBD.

The in-vacuum stepper motor for turning the filter wheel has a TBD MTBF.

The TRANSMON QPD is not within the scope of AOS.

4.3.1.5.2 ETM Telescope Maintainability

The following components are susceptible to failure:

1) OSEM

2) Suspension wires

3) Stepper motor

If either of these components fails, the suspension assembly will be removed from the vacuum chamber and repaired. The physical location of the suspension will be preserved by means of alignment fixtures. The pointing angle of the ETM Telescope assembly will be reproduced by repeating the initial alignment procedure.

4.3.1.5.3 ETM Telescope Environmental Conditions

4.3.1.5.3.1 Natural Environment

4.3.1.5.3.1.1 Temperature and Humidity

The ETM Telescope is designed to operate in the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 4 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

4.3.1.5.3.1.2 Atmospheric Pressure

The ETM Telescope will function under normal atmospheric pressure conditions

4.3.1.5.3.1.3 Seismic Disturbance

The ETM Telescope will be mounted to isolated optical tables within the vacuum chambers and will not be subjected substantially to the ground seismic disturbances.

4.3.1.5.3.2 Induced Environment

4.3.1.5.3.2.1 Electromagnetic Radiation

NA

4.3.1.5.3.2.2 Acoustic

NA

4.3.1.5.3.2.3 Mechanical Vibration

NA

4.3.1.6 ETM Telescope 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.

4.4 OMMT

4.4.1 OMMT Characteristics

The OMMT is a three-mirror beam reducing telescope with suspended spherical mirrors. The mirrors will be super-polished to minimize scattering, and ion-beam coated with HR dielectric coatings to maximize reflectivity.

4.4.1.1 OMMT Mirror Performance Characteristics

4.4.1.1.1 Clear Aperture

The clear aperture of the OMMT1 mirror is 285 mm diameter, which is the same as the clear aperture of the input mode matching telescope mirror MMT3. The demagnified beam diameter is approximately 20 mm on the surface of OMMT2, which has a clear aperture of 70 mm. The beam diameter is also 20 mm on the surface of OMMT3, which has a clear aperture of 70 mm. Therefore, the 285 mm diameter APS beam passes through the OMMT without vignetting. This meets the requirement 3.4.1.

4.4.1.1.2 Demagnification Ratio

The OMMT mirrors will have identical specifications as the MMT mirrors. The demagnification ratio of the OMMT is approximately 1/15, the inverse of the input mode matching telescope magnification.

4.4.1.1.3 Wavefront Distortion

4.4.1.1.3.1 OMMT Distortion

The off-axis angle spherical mirrors of the OMMT beam reducing telescope cause negligible astigmatic distortion of the wavefront, because the off-axis angles are small. The majority of the distortion is due to the specified 0.125 waves of surface distortion @ 0.633 nm wavelength (0.074 waves @ 1064 nm) on each of the three mirrors. The total distortion was calculated using ZEMAX. The ray-trace model of the OMMT is shown in Figure 15. Zernike polynomials were used to place a total distortion of 0.074 waves @ 1064 nm on each of the three mirror surfaces, divided equally between spherical aberration, coma, and astigmatism. The total wavefront distortion of the OMMT is < 0.085 waves p-v @ 1064 nm, as shown in Figure 16**.**

This meets the requirement 3.4.2.

4.4.1.1.3.2 Distortion of APS Beam

The wavefront distortions of all the elements in the APS optical train are shown below:

1, OMMT	0.085 waves
1, Faraday isolator	0.42 waves
2, steering mirrors	0.059 waves
2, Brewster's viewport surfaces	0.059 waves

Based on these numbers, the total wavefront distortion of the APS beam at the ISC detection bench is <0.44 waves @ 1064 nm wavelength.

4.4.1.1.4 Pointing Accuracy

4.4.1.1.4.1 OMMT1

4.4.1.1.4.1.1 Coarse Pointing

The OMMT1 mirror will be suspended by a modified LOS. The LOS has an angular pointing range of 0.5 mrad p-p (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements). This meets the requirement 3.4.3.1.1.

4.4.1.1.4.1.2 Fine Pointing

The LOS suspension for OMMT1 has a pitch and yaw sensor noise of < 2.5×10^{-11} radians/rtHz (see T960). Assuming a 1 Hz bandwidth, this will provide << 50 urad pointing precision in pitch and yaw.

This meets the requirement 3.4.3.1.2.

4.4.1.1.4.2 OMMT2 and OMMT3

4.4.1.1.4.2.1 Coarse Pointing

The OMMT2 and OMMT3 mirrors will be suspended by an SOS. The SOS suspension has a pitch and yaw range of 28 mrad p-p (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements).

This meets the requirements 3.4.3.2.1 and 3.4.3.3.1.

4.4.1.1.4.2.2 Fine Pointing

The SOS suspension for OMMT2 and OMMT3 has a pitch and yaw sensor noise of < 1.5×10^{-9} radians/rtHz (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements). Assuming a 1 Hz bandwidth, this will provide << 50 urad pointing precision in pitch and yaw.

This meets the requirements 3.4.3.2.2 and 3.4.3.3.2.

4.4.1.1.4.3 Damping

The LOS and SOS OSEM feedback loops provide damping with a Q < 10 for pitch, yaw, longitudinal, and transverse motions (see T960151-02 Large and Small Optics Suspension Electronics Design Requirements). This meets the requirements 3.4.4.

4.4.1.1.5 Surface Quality

The OMMT mirror surfaces will be super polished with a micro roughness < 0.8 Angstrom rms and coated with ion-beam deposition, dielectric high reflectance and antireflection coatings. This meets the requirement 3.4.5.

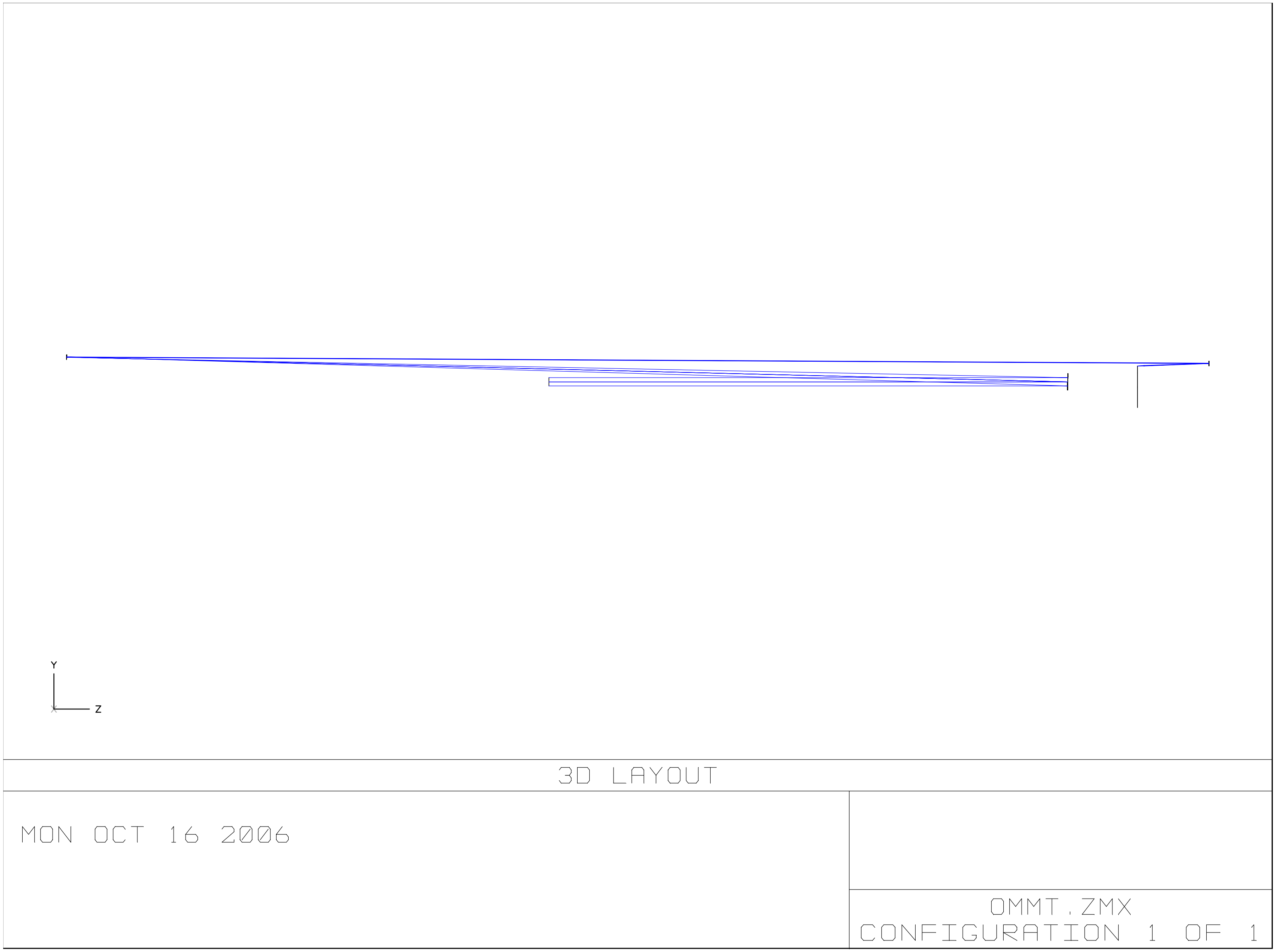

Figure 15: OMMT, ray model

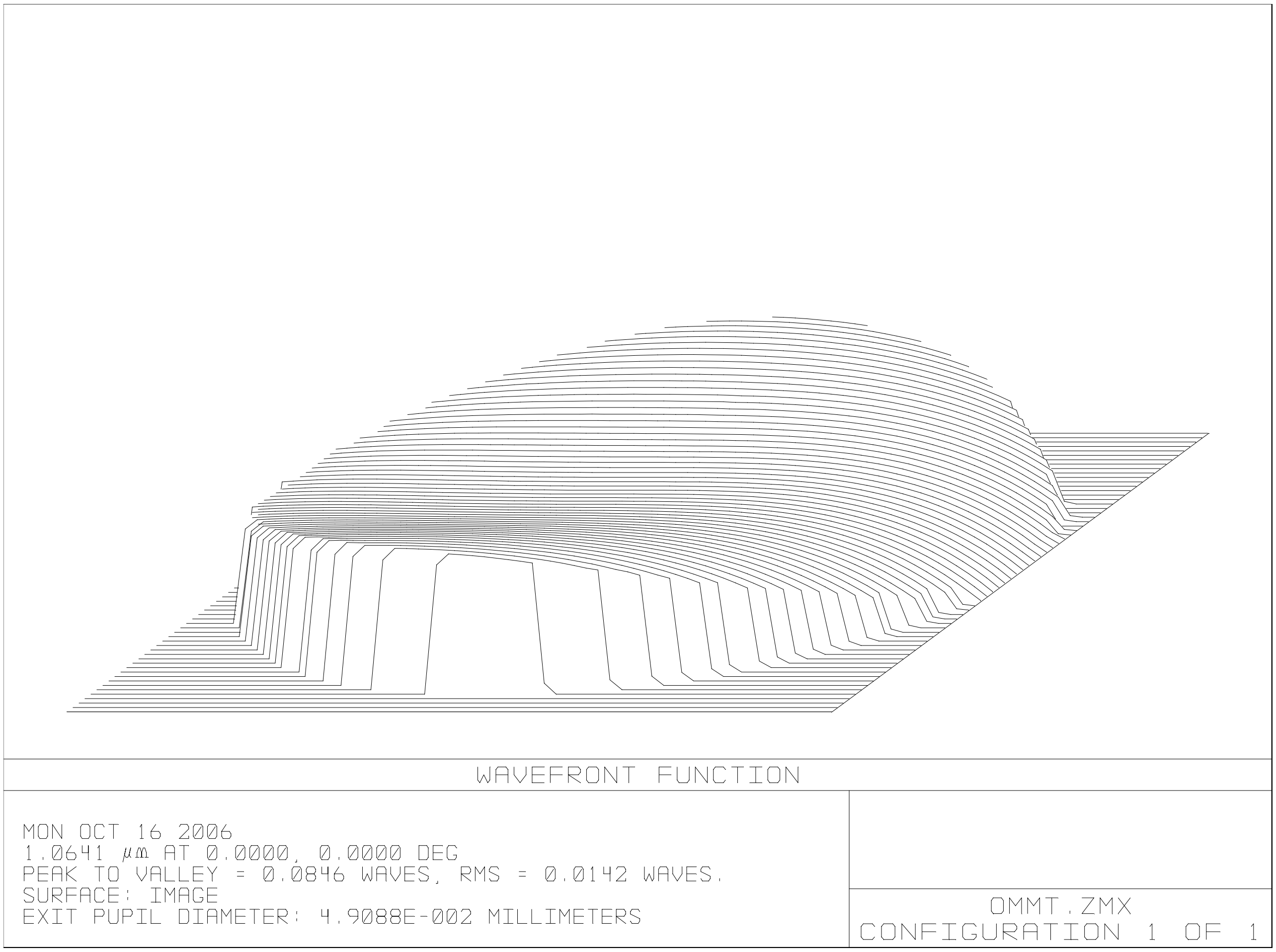

Figure 16: OMMT, wavefront distortion

4.4.1.2 OMMT Physical Characteristics

4.4.1.2.1 OMMT1

OMMT1 is the primary mirror of the OMMT. It is suspended in a modified LOS on HAM 5, for the non-folded IFO. The overall dimensions of the LOS are shown in Figure 17.

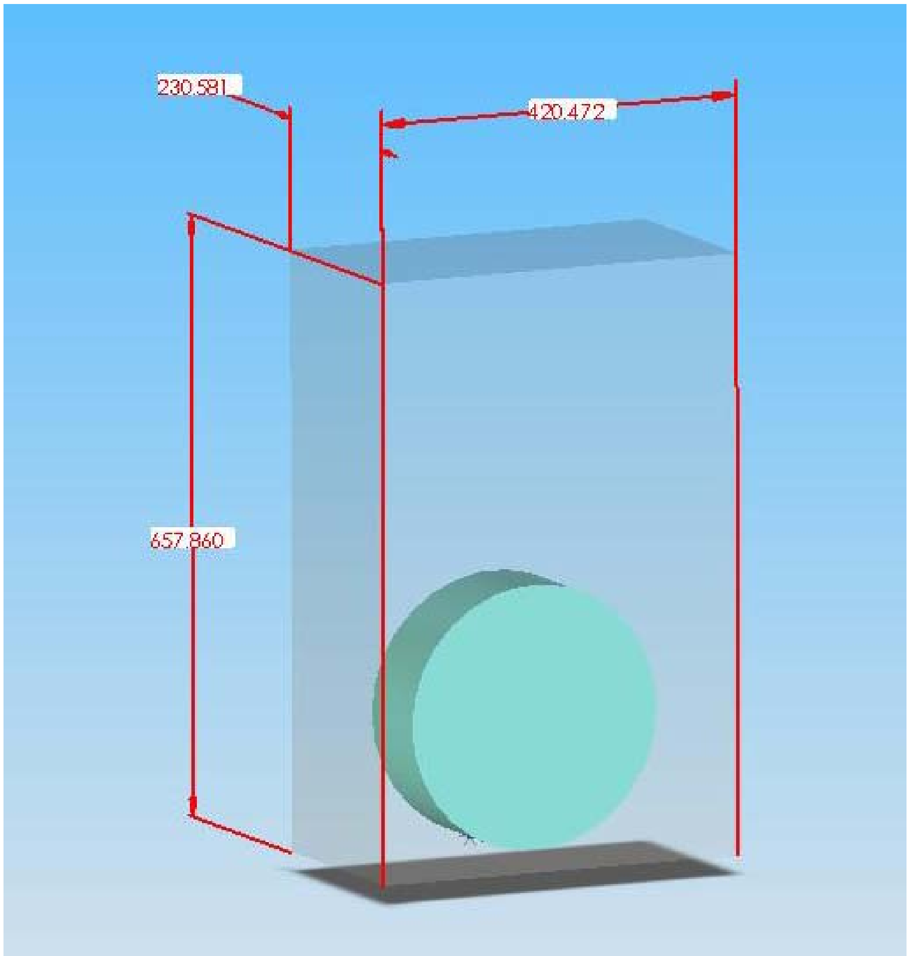

Figure 17: Outline drawing of modified LOS

Characteristics of OMMT1

Radius of curvature	28961.4 mm
Outside diameter	265 mm
Clear Aperture	258 mm
Thickness	100 mm

4.4.1.2.2 OMMT2

OMMT2 is the secondary mirror of the OMMT. It is suspended in an Initial LIGO SOS on HAM 4. A SW model of the suspended OMMT2 is shown in Figure 18. The optimal separation between the OMMT1 and OMMT2 mirrors is 15446 mm.

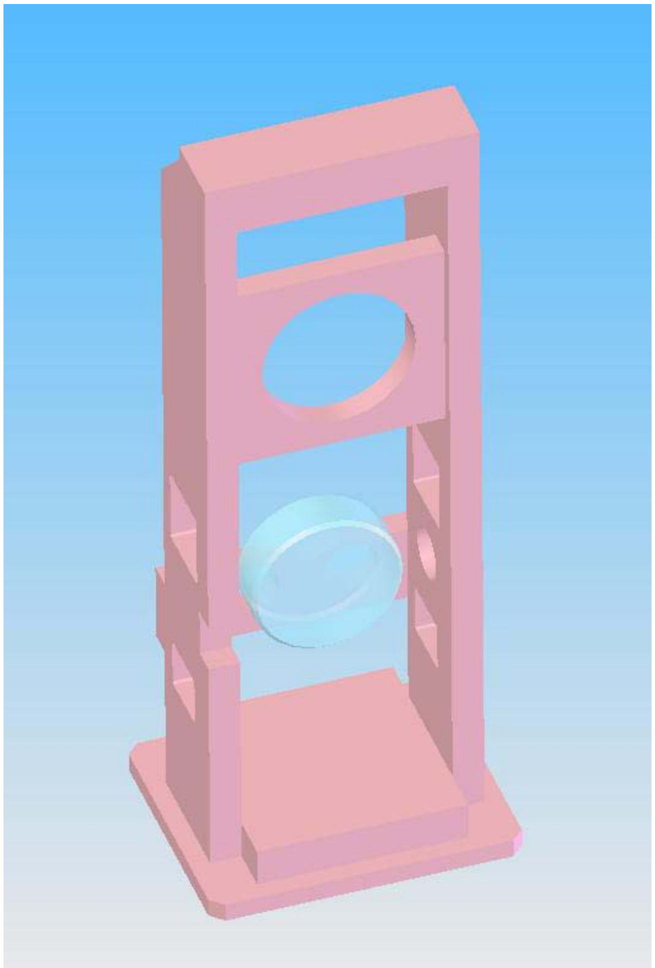

Figure 18: SOS Assembly

Characteristics of OMMT2

Radius of curvature	1930 mm
Outside diameter	75 mm
Clear Aperture	70 mm
Thickness	25 mm

4.4.1.2.3 OMMT3

OMMT3 is a steering mirror for the OMMT. It is suspended in an SOS on HAM 4, for the non-folded IFO. A SW model of the suspended OMMT2 is shown in Figure 18.

Characteristics of OMMT1

Radius of curvature	flat
Outside diameter	75 mm
Clear Aperture	70 mm
Thickness	25 mm

4.4.1.2.4 Electrical characteristics

4.4.1.2.4.1 OMMT1 Suspension

CDS will provide appropriate (TBD) electrical currents for the OSEM to control the pitch and yaw angles of the LOS.

4.4.1.2.4.2 OMMT2 and OMMT3 Suspension

CDS will provide appropriate (TBD) electrical currents for the OSEM to control the pitch and yaw angles of the SOS.

4.4.1.3 OMMT Interface Definitions

4.4.1.3.1 Interfaces to other LIGO detector subsystems

4.4.1.3.1.1 Mechanical Interfaces

The OMMT1 and OMMT3 suspensions will be clamped to the optical table in HAM5, and the OMMT2 suspension will be clamped to the optical table in HAM4; for the non-folded IFO.

4.4.1.3.1.2 Electrical Interfaces

The control currents for the three OMMT suspensions will enter the vacuum chambers through appropriate electrical feed-through (TBD), and will be connected to the suspension by means of appropriate electrical cables and connectors (TBD).

4.4.1.3.1.3 Optical Interfaces

OMMT1 will reflect the APS beam that transmits through the AR face of the SRM. The output beam reflecting from OMMT3 will be steered into the input aperture of the output Faraday isolator on HAM5, for the non-folded IFO.

4.4.1.3.1.4 Stay Clear Zones

NA

4.4.1.3.2 Interfaces external to LIGO detector subsystems

4.4.1.3.2.1 Mechanical Interfaces

4.4.1.3.2.2 Electrical Interfaces

4.4.1.3.2.3 Stay Clear Zones

4.4.1.4 OMMT Mirror Reliability

4.4.1.4.1 Mean Time Before Failure

The MTBF of the OMMT mirrors is expected to be the same as was experienced with the MMT mirrors of Initial LIGO. TBD

4.4.1.4.2 OMMT Mirror Maintainability

The following components are susceptible to failure:

3) OSEM

4) Suspension wires

If either of these components fails, the suspension assembly will be removed from the vacuum chamber and repaired. The physical location of the suspension will be preserved by means of alignment fixtures. The pointing angle of the mirrors will be reproduced by means of the optical lever associated with the particular suspended mirror.

4.4.1.4.3 OMMT Mirror Environmental Conditions

4.4.1.4.3.1 Natural Environment

4.4.1.4.3.1.1 Temperature and Humidity

The OMMT is designed to operate in the humidity and temperature controlled environment of the enclosed LIGO LVEA.

Table 5 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

4.4.1.4.3.1.2 Atmospheric Pressure

The OMMT shall function under normal atmospheric pressure conditions

4.4.1.4.3.1.3 Seismic Disturbance

The OMMT SUS will be mounted to isolated optical tables within the vacuum chambers and will not be subjected substantially to the ground seismic disturbances.

4.4.1.4.3.2 Induced Environment

4.4.1.4.3.2.1 Electromagnetic Radiation

NA

4.4.1.4.3.2.2 Acoustic

NA

4.4.1.4.3.2.3 Mechanical Vibration

NA

4.4.1.5 OMMT Mirror 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.

4.5 Design and Construction

4.5.1 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.

4.5.1.1 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.

4.5.1.2 Processes

4.5.1.2.1 Cleaning

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

4.5.1.3 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.

4.5.2 Workmanship

All components will be manufactured according to good commercial practice.

4.5.3 Interchangeability

Common elements with ordinary dimensional tolerances will be interchangeable.

4.5.4 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.

4.5.5 Human Engineering

NA

4.6 Assembly and Maintenance

Assembly procedures will be developed in conjunction with the hardware design.

4.7 Documentation

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

4.7.1 Specifications

The manufacturer's specifications for the purchased components will apply.

4.7.2 Design Documents

Revised drawings and calibration documents will be produced as necessary.

4.7.3 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.

4.7.4 Technical Manuals and Procedures

4.7.4.1 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

4.7.4.2 Manuals

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

4.7.5 Documentation Numbering

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

4.7.6 Test Plans and Procedures

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

4.8 Logistics

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

4.9 Precedence

4.10 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

No reliability testing is anticipated.

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.

Witness samples will be acceptable proof of the properties of HR and AR coatings applied to the optical surfaces.

5.2.2 Demonstration

A demonstration of the visual quality of the autocollimator alignment pattern retro-reflected through the telescope will be accepted as verification of acceptable wavefront deformation of the focused telescope.

5.2.3 Test

Appropriate tests will be implemented to verify the specifications of the purchased components. TBD

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 6 Quality Conformance Inspections

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