

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Document Type LIGO-T970080 - 09-D 6/30/97
(Infrared) Pre-stabilized Laser (PSL) Design Requirements
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Distribution of this draft:

LIGO Nd:YAG Prestabilized Laser (PSL) Subsystem Design
Requirements Review Board (refer to LIGO-L970426-00-D)

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1 INTRODUCTION

1.1. Purpose

The purposes of this document are to define the contents and scope of the Pre-Stabilized Laser subsystem (PSL), to describe and specify the design requirements for the PSL, and to identify the interfaces (mechanical, optical, and electrical) with both the other Detector subsystems and with other LIGO systems.

The principal intended audience for this document is the LIGO Detector team.

1.2. Scope

PSL (including the **CDS** component) provides the pre-stabilized laser light for the interferometers to the **IOO** subsystem. It is responsible for stabilizing power fluctuations in the laser light to required levels both at the input to **IOO** and at the input to **COC**. It is responsible for stabilization of frequency fluctuations to the level required at the input to **IOO**. It accommodates frequency control signals generated by both **IOO** and **LSC** which allow those subsystems to further reduce frequency fluctuations via feedback control to PSL, but is NOT responsible for stabilization to levels beyond those required at the input to **IOO**.

PSL shares an optical table with the **IOO**, and because PSL will be installed before **IOO**, PSL assumes responsibility for procurement and installation of the shared optical tables and optical table enclosures at the sites according to requirements developed jointly by **IOO** and PSL. PSL does NOT assume responsibility for the procurement and testing of the optical table vibration isolation system; **IOO** is responsible for those tasks.

1.3. Definitions

- Gaussian beam: A beam of electromagnetic radiation, in which the transverse electric field varies as $E = E_0 e^{-r^2/w^2}$, where w is the beam spot size and E_0 is the electric field strength at $r=0$.
- Lightwave: Lightwave Electronics, Inc., 1161 San Antonio Road, Mountain View, CA 94043
- Lightwave 10-W Laser: The 10-W, Nd:YAG laser being developed by Lightwave Electronics, Inc. under contract with LIGO (contract number PC198201).
- LIGO Standard Spectrum: Model of “pristine” seismic background vibration levels at the LIGO observatory sites. Refer to *Vibration and Acoustic Requirements for the Laser and Vacuum Equipment Area (LVEA) and Vacuum Equipment Areas (VEA) for the LIGO Facilities*, LIGO-T950113-05-0.
- Spot size: The characteristic size for Gaussian laser beams, defined as the distance (radius) at which the electric field drops to $1/e$ times the maximum value, E_0 (at $r = 0$).

1.4. Acronyms

AOM Acousto-Optic Modulator or Modulation

BF	Beam Finding (diagnostic mode)
CDS	Control and Data Systems (detector subsystem)
COC	Core Optics Components (detector subsystem)
CPR	Calibrated Power Reduction
CR	Cavity Ringdown (diagnostic mode)
GW	Gravitational Wave
IOO	Input Optics (detector subsystem)
LSC	Length Sensing/ Control detector subsystem
LSS	LIGO Standard Spectrum (of seismic background vibration levels)
LVEA	Laser and Vacuum Equipment Area (of the LIGO observatory facilities)
MDT	Mean Down Time
MTBF	Mean Time Between Failures
PSL	Pre-stabilized Laser (detector subsystem)
RH	Relative Humidity
RMS	Root Mean Squared
SD	System Diagnostics (diagnostic mode)
SRD	Science Requirements Document, LIGO-E950018-00.
SYS	Detector System Engineering
TBD	To Be Determined
TEM	Transverse Electromagnetic (mode)

1.5. Applicable Documents

1.5.1. LIGO Documents

- *Detector Subsystems Requirements*, LIGO-E960112-06-D
- *Frequency Stabilization: Servo Configuration & Subsystem Interface Specification*, LIGO-T970088-00-D
- *Frequency Stabilization in LIGO*, LIGO-T960164-00-D
- *Prestabilized Laser Design Requirements*, LIGO-T950030-03-D
- *Input Output Optics Design Requirements Document*, LIGO-T960093-00-D
- *Input / Output Optics Conceptual Design*, LIGO-T960170-00-D
- *Design and Fabrication of Nd³⁺ Lasers*, contract between Caltech and Lightwave Electronics, Inc., LIGO-C960880-A-R
- *Recycling Cavity and Mode Cleaner Cavity Baseline Dimensions*, LIGO-T970068-00-D.
- *NPRO-PSL Performance Data and System Documentation*, LIGO-T970052-00-D

- *Vibration and Acoustic Requirements for the Laser and Vacuum Equipment Area (LVEA) and Vacuum Equipment Areas (VEA) for the LIGO Facilities*, LIGO-T950113-05-0.
- *Civil Construction Facilities Design Configuration Control Document, Final Issue, July 3, 1996*, LIGO-C960703-0.
- *LIGO 10-W Laser Specifications*, LIGO-E970055-01-D.
- *Science Requirements Document*, LIGO-E950018-00.
- *LIGO EMI Control Plan And Procedures*, LIGO-E960036-A-E.
- *Alignment Sensing/Control Design Requirements Document*, LIGO-T952007-04-I.
- *Input / Output Optics Conceptual Design*, LIGO-T960170-00-D.
- *Prestabilized Laser Design Requirements*, LIGO-T950030-03-D.
- *LIGO Naming Conventions*, LIGO E950111-A-E

1.5.2. Non-LIGO Documents

- *Ultrahigh-spectral-purity laser for the VIRGO experiment*, F. Bondu, P. Fritschel, C. N. Man, and A. Brillat, *Optics Letters*, **21**, 582 (1996).
- *Monolithic, unidirectional single-mode Nd:YAG ring laser*, Thomas J. Kane and Robert L. Byer, *Optics Letters*, **10**, 65 (1985).

2 GENERAL DESCRIPTION

PSL provides the laser radiation for the LIGO interferometers. The heart of the PSL subsystem is the LIGO 10-W Laser being developed under contract with Lightwave Electronics, Inc. in Mountain View, CA. The goal of the PSL development work is to design a system capable of accommodating the LIGO 10-W Laser and reducing its output beam frequency and power fluctuations to the levels required for the LIGO initial detectors. The PSL system will be capable of remote control and monitoring via computer and will incorporate internal diagnostics as well as features that allow other subsystems to diagnose their performance.

Detector availability requirements determine that the PSL subsystem acquire lock quickly and reliably and operate without loss of lock for long periods of time. In addition, PSL must maintain performance while accommodating control signals from the IOO and LSC subsystems that enable other subsystems to achieve required performance.

Designing and fabricating laser systems with the reliability and maintainability required to enable the detectors to meet availability goals are expected to present a major challenge for the PSL subsystem.

An earlier PSL requirements document¹ described a light source based on an Argon-Ion laser. The requirements described here and the associated design builds on that background, but is substantially new; no knowledge of the earlier documents is presumed or necessary.

1. *Prestabilized Laser Design Requirements*, LIGO T950030-03-D

2.1. Specification Tree

This document is part of an overall LIGO detector requirement specification tree. This particular document is highlighted in Figure 1.

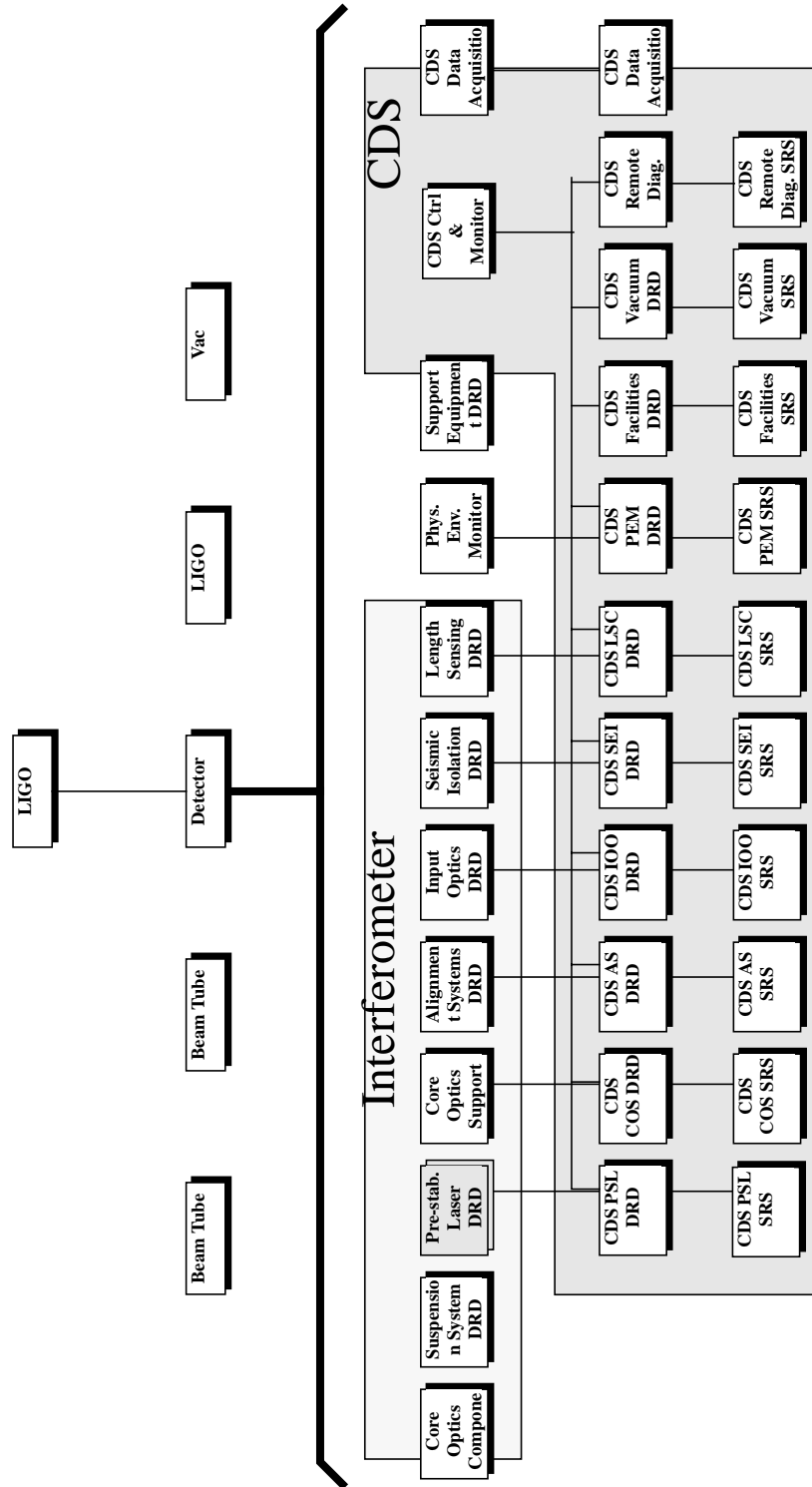


Figure 1: LIGO detector requirement specification tree

2.2. Product Perspective

PSL contains the laser source for the LIGO interferometers and therefore is situated at the beginning of the optical train. As shown schematically in Figure 2, PSL passes the pre-stabilized laser radiation to **IOO** which in turn passes it to **COC**. Laser frequency correction signals are passed to PSL from both **IOO** and **LSC**. The principal signal interface for PSL is with **CDS**.

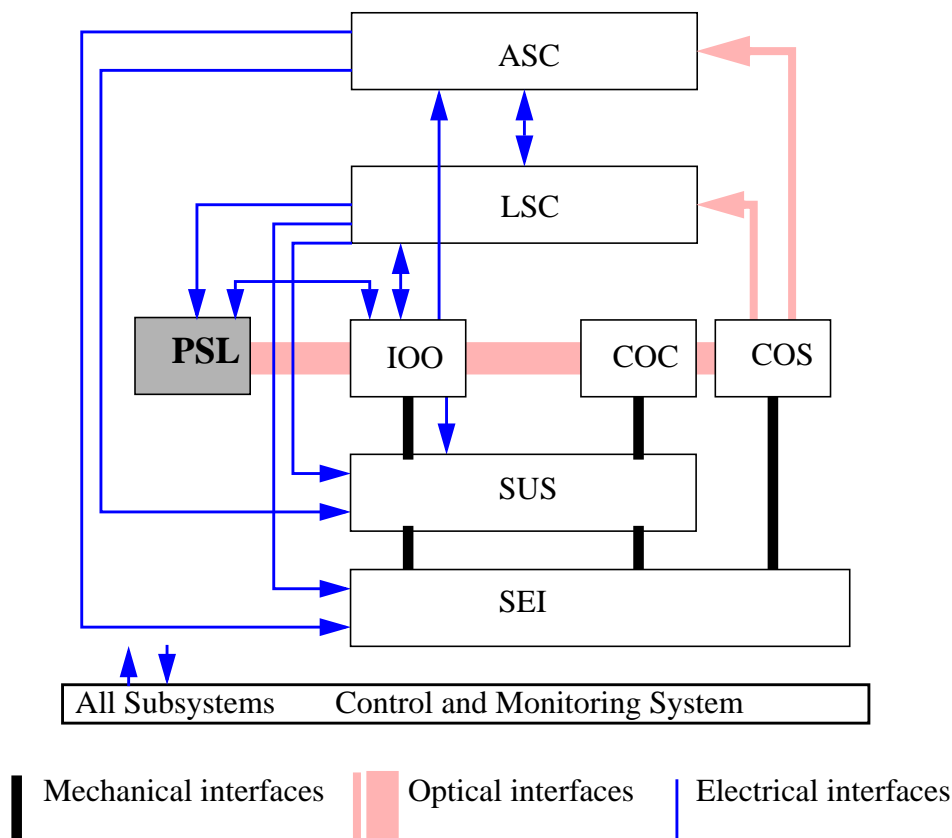


Figure 2: Block diagram showing the relationship of PSL to the other detector subsystems.

2.3. Product Functions

The PSL provides the following functions:

- Generation of the laser radiation.
- Power stabilization of the laser radiation.
- Frequency stabilization of the laser radiation.
- Calibrated power reduction, frequency modulation, and power modulation of the laser radiation in order to accommodate PSL-external system diagnostic functions.
- PSL-internal diagnostics.

- Remote computer control and monitoring.

2.4. General Constraints

LIGO must operate continuously, therefore this subsystem must be designed with high reliability and low mean time to repair. The PSL subsystem incorporates several feedback control loops that enable the frequency and power of the laser radiation to be stabilized to very low fluctuation levels. Those control loops must acquire lock quickly and reliably via a computer-automated sequence and maintain lock for long periods of time.

2.5. Assumptions and Dependencies

The vibration and acoustic levels in the Laser and Vacuum Equipment Areas (LVEA) at the LIGO observatories are assumed to meet the requirements given in *Vibration and Acoustic Requirements for the Laser and Vacuum Equipment Area (LVEA) and Vacuum Equipment Areas (VEA) for the LIGO Facilities*, LIGO-T950113-05-0.

The temperature and pressure in the LVEA are assumed to meet the design conditions given in the Civil Construction Facilities *Design Configuration Control Document, Final Issue, July 3, 1996*, LIGO-C960703-0. Specifically, a design temperature of $72^{\circ} \pm 3.5^{\circ} \text{F}$ and pressure of 0.15 in. wg above ambient.

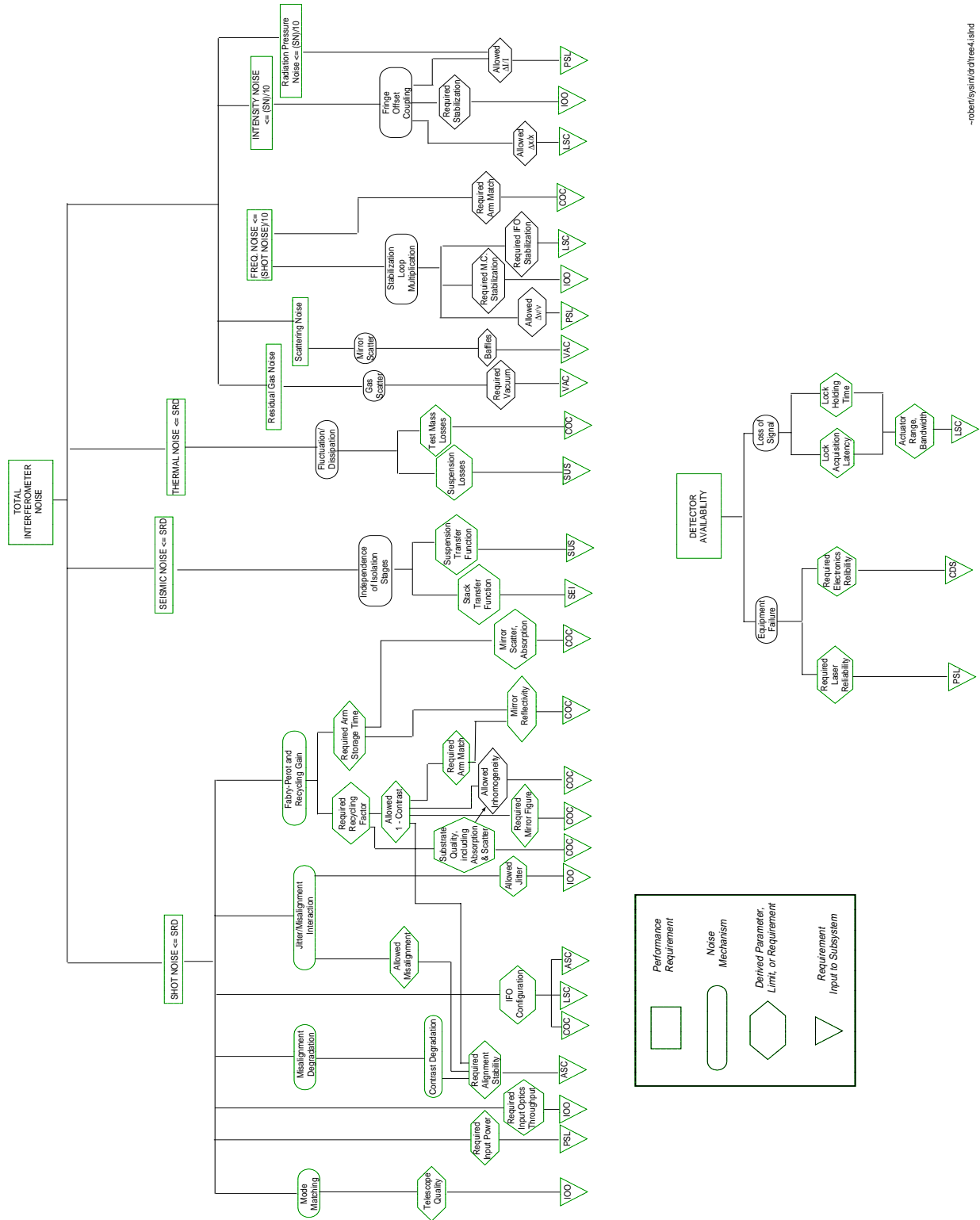
The LIGO 10-W laser meets the specifications given in *LIGO 10-W Laser Specifications*, LIGO-E970055-01-D.

3 REQUIREMENTS

3.1. Introduction

“Figure 3 is the flowdown tree for the principal Gaussian noise terms to requirements imposed on detector subsystems. The top-level requirements are specified in the SRD, and enter the trees as “Total Detector Noise” and “Detector Availability.” They determine subsystem requirements via noise coupling mechanisms or via states that affect availability, respectively. The internal designs of the subsystems are constrained to meet these lowest-level requirements, but otherwise remain free for optimization of performance and reduction of cost. In general, SYS specifies down to a

level where there are no more inter-subsystem trades to be made.”¹



-roberts/systems/dt/dtreq-t1.shd

Figure 3: Gaussian noise flowdown

1. From *Detector Subsystems Requirements*, LIGO-E960112-06-D

3.2. Characteristics

3.2.1. Performance Characteristics

3.2.1.1 Laser Wavelength

The laser wavelength shall be 1064 nm.

3.2.1.2 PSL TEM₀₀ Output Power

The nominal PSL output power shall be greater than or equal to 8.5 W in a circular TEM₀₀ mode.

3.2.1.3 PSL Non-TEM₀₀ Output Power (from IOO/SYS)

The total output power in all modes except the circular TEM₀₀ mode shall be less than or equal to 500 mW.

3.2.1.4 PSL TEM₀₀ Output Power Variations

The low-frequency variations in the PSL output power shall be less than 1% peak-to-peak over any 24-hour period.

3.2.1.5 Fractional Light Power Fluctuations at IOO Input

The amplitude spectral density of the fractional light power fluctuations at the input to the IOO shall be $\delta P(f)/P < 10^{-6} 1/\sqrt{\text{Hz}}$ for $100 \text{ Hz} < f < 10 \text{ kHz}$ and rising as $f^{-3/2}$ for $40 \text{ Hz} < f < 100 \text{ Hz}$.

3.2.1.6 Fractional Light Power Fluctuations at COC Input

The amplitude spectral density of the fractional light power fluctuations at the input to the COC (recycling mirror) shall be $\delta P(f)/P < 10^{-8} 1/\sqrt{\text{Hz}}$ for $100 \text{ Hz} < f < 10 \text{ kHz}$ and rising as $f^{-3/2}$ for $40 \text{ Hz} < f < 100 \text{ Hz}$ for both the carrier and for the sidebands used for GW detection.

3.2.1.7 Shot-noise-limited Power Fluctuations

The amplitude spectral density of relative power fluctuations in the output beam of the laser, measured at the input to the IOO, at frequencies above 24.5 MHz and 29.5 MHz (the modulation frequencies of the sidebands used for gravity wave detection for the 4-km and 2-km interferometers, respectively¹), shall be less than 1.005 times the shot noise limit for 600 mW of laser power. (This is the expected power level at the dark port of the interferometer).

3.2.1.8 Frequency Fluctuations

The amplitude spectral density of the frequency fluctuations at the input to the IOO shall be as specified in Table 1, below.

1. Refer to *Recycling Cavity and Mode Cleaner Cavity Baseline Dimensions*, LIGO-T970068-00-D.

<i>Frequency Range</i>	<i>Allowed Frequency Fluctuations</i>
40 Hz to 100 Hz	$< 0.1 \times (100 \text{ Hz}/f)^{2.5} \text{ Hz}/\sqrt{\text{Hz}}$ (from SYS)
100 Hz to 1 kHz	$< 0.1 \times (100 \text{ Hz}/f) \text{ Hz}/\sqrt{\text{Hz}}$ (from SYS)
1 kHz to 10 kHz	$< 1.0 \times 10^{-2} \text{ Hz}/\sqrt{\text{Hz}}$ (from SYS)

Table 1: Allowed PSL Output Beam Frequency Fluctuations**3.2.1.9 PSL Output Beam Relative Pointing Angle Fluctuations**

The relative pointing angle fluctuations of the PSL output beam, $\delta\theta/(\theta_d/2)$, at the interface with **IOO** shall be as specified in Table 2, below. $\theta_d/2$, the divergence half angle, is given by $\theta_d/2 = \lambda/(\pi \times w_0)$, where w_0 is the spot size at the beam waist.

<i>Frequency Range</i>	<i>Allowed Relative Pointing Angle Fluctuations</i>
DC to 40 Hz	< 0.1 peak-to-peak (TBD by IOO)
40 Hz to 150 Hz	$< 2 \times 10^{-6} \times (150/f)^2 \text{ 1}/\sqrt{\text{Hz}}$ (from SYS)
> 150 Hz	$< 2 \times 10^{-6} \text{ 1}/\sqrt{\text{Hz}}$ (from SYS)

Table 2: Allowed PSL Output Beam Relative Pointing Angle Fluctuations**3.2.1.10 PSL Output Beam Relative Displacement Fluctuations**

The relative displacement fluctuations of the PSL output beam, $\delta x/w_0$, at the interface with **IOO** shall be as specified in Table 3, below.

<i>Frequency Range</i>	<i>Allowed Relative Displacement Fluctuations</i>
DC to 40 Hz	< 0.1 peak-to-peak (TBD by IOO)
40 Hz to 150 Hz	$< 1.3 \times 10^{-5} \times (150/f)^2 \text{ 1}/\sqrt{\text{Hz}}$ (from SYS)
> 150 Hz	$< 1.3 \times 10^{-5} \text{ 1}/\sqrt{\text{Hz}}$ (from SYS)

Table 3: Allowed PSL Output Beam Relative Displacement Fluctuations**3.2.1.11 Output Beam Polarization Ratio (from IOO/SYS)**

The polarization ratio of the PSL output beam at the input to **IOO** shall be greater than 100:1.

3.2.1.12 Output Beam Polarization Direction (from IOO/SYS)

The electric field (polarization direction) of the PSL output beam at the input to **IOO** shall be oriented normal to the surface of the shared **IOO/PSL** optical table within ± 1 degree.

3.2.1.13 Output Beam Polarization Angle Fluctuations (from IOO/SYS)

The amplitude spectral density of fluctuations in the polarization angle of the PSL output beam with respect to the plane of the shared PSL/IOO optical table shall be less than **TBD by IOO/SYS** radians/ $\sqrt{\text{Hz}}$.

3.2.1.14 Allowed Scattered Light Level (from COS/SYS)

TBD-by COS/SYS

3.2.1.15 PSL-External Diagnostic Modes

In order to enable diagnostics of subsystems other than the PSL subsystem, the PSL is required to operate in various diagnostic modes as described below.

3.2.1.15.1 PSL Beam Finding (BF) Mode (from LSC/SYS)

In order to enable locating optical beams prior to fine alignment, the PSL shall allow output power modulation by remote command. The modulation parameters shall be as specified in Table 4, below.

<i>Parameter</i>	<i>Specification</i>
1. Modulation Waveform	Square wave, 10%-90% transition time < 50 msec
2. Modulation Depth	50% \pm 10 %.
3. Modulation Frequency	2.0 Hz \pm 0.1 Hz.

Table 4: PSL BF Mode Parameters

During operation in this mode, the power stabilization and frequency stabilization control loops shall remain locked and active, but with reduced performance requirements as described below.

3.2.1.15.1.1 PSL BF Mode Power Fluctuations (from LSC/SYS)

During operation in BF mode, the rms relative power fluctuations at the PSL output, measured with a 1 sec or greater integration time, shall be less than 1×10^{-3} .

3.2.1.15.1.2 PSL BF Mode Frequency Fluctuations (from LSC/SYS)

During operation in BF mode, the frequency fluctuations at the PSL output shall be such that the **IOO** Mode Cleaner can remain locked to the laser (performance of **IOO** in BF mode **TBD** by **IOO/SYS**).

3.2.1.15.2 PSL Cavity Ringdown (CR) Mode (from LSC/SYS)

In order to measure ringdown times of the various optical cavities in the interferometers, the PSL shall allow output power modulation by remote command. The modulation parameters shall be as specified in Table 5, below.

<i>Parameter</i>	<i>Specification</i>
1. Modulation Waveform	Square wave and Sine wave
2. Modulation Depth	Variable between 1% and 10% in steps no coarser than 1%.
3. Modulation Frequency	Square wave: variable between 0.01 Hz and 100 Hz in steps no larger than ten per decade. TBD by COC/SYS Sine wave: variable between 0.01 Hz and 10 kHz in steps no larger than ten per decade. TBD by COC/SYS
3. Slew Time	The Min-to-Max and Max-to-Min slew times shall be less than 0.05 sec TBD by COC/SYS .

Table 5: PSL CR Mode Parameters

During operation in this mode, the power stabilization and frequency stabilization control loops shall remain locked and active, but with reduced performance requirements as described below.

3.2.1.15.2.1 PSL CR Mode Power Fluctuations (from LSC/SYS)

During operation in CR mode, the rms relative power fluctuations at the **PSL** output, measured with a 1 sec or greater integration time, shall be less than 1×10^{-3} **TBD** by **LSC/SYS**.

3.2.1.15.2.2 PSL CR Mode Frequency Fluctuations (from LSC/SYS)

During operation in CR mode, the frequency fluctuations at the PSL output shall be no greater than ten times the required level during normal operational mode (refer to Section 3.2.1.8). **TBD** by **LSC/SYS**.

3.2.1.15.3 PSL System Diagnostics (SD) Mode

In order to perform system-level signal diagnostics, the PSL shall allow output power modulation and output frequency modulation by remote command.

During operation in this mode, the power stabilization and frequency stabilization control loops (either or both) shall remain locked and active with the performance requirements given in Section 3.2.1.15.3.3 and Section 3.2.1.15.3.4, or unlocked (inactive) at the user's discretion. In the 'inactive' mode, both frequency and power modulation inputs will be held at their last operational value by offset voltages no more noisy than the operational mode inputs.

3.2.1.15.3.1 Relative Power Modulation

The relative power modulation parameters shall be as specified in Table 6, below.

<i>Parameter</i>	<i>Specification</i>
1a. Modulation Waveform	Sine wave.
1b. Modulation Amplitude	Variable between 10^{-8} and 10^{-3} rms in steps no coarser than ten per decade.
1c. Modulation Frequency	Variable from 1 Hz to 10 kHz in steps no coarser than ten per decade.
2a. Modulation Waveform	Pseudo-random (noise-like).
2b. Modulation Amplitude Spectral Density	Variable between 10^{-8} and $10^{-3} 1/\sqrt{\text{Hz}}$ in steps no coarser than ten per decade.
2c. Modulation Bandwidth	> 10 kHz

Table 6: PSL SD Mode Power Modulation Parameters

3.2.1.15.3.2 Frequency Modulation

The frequency modulation parameters shall be as specified in Table 7, below.

<i>Parameter</i>	<i>Specification</i>
1a. Modulation Waveform	Sine wave.
1b. Modulation Amplitude	Variable between 10^{-7} and 10^{-2} Hz rms in steps no coarser than ten per decade.
1c. Modulation Frequency	Variable from 1 Hz to 10 kHz in steps no coarser than ten per decade.
2a. Modulation Waveform	Pseudo-random (noise-like).
2b. Modulation Amplitude Spectral Density	Variable between 10^{-7} and $10^{-2} \text{ Hz}/\sqrt{\text{Hz}}$ rms in steps no coarser than ten per decade.
2c. Modulation Bandwidth	> 10 kHz

Table 7: PSL SD Mode Frequency Modulation Parameters

3.2.1.15.3.3 PSL SD Mode Power Fluctuations

During operation in SD mode, the fractional power fluctuations at the **IOO** input shall remain at the level required during normal operational mode a) except at the modulation frequency for sinusoidal modulation and b) during noise-like modulation, the relative power fluctuations require-

ments at the input to **IOO** (Section 3.2.1.5) and at the input to **COC** (Section 3.2.1.6) are relaxed in proportion to the modulation amplitude.

3.2.1.15.3.4 PSL SD Mode Frequency Fluctuations

During operation in SD mode, the frequency fluctuations at the **IOO** input shall remain at the level required during normal operational mode a) except at the modulation frequency for sinusoidal modulation and b) during noise-like modulation, the frequency fluctuations requirement at the input to **IOO** (Section 3.2.1.8) is relaxed in proportion to the modulation amplitude.

3.2.1.15.4 PSL Calibrated Power Reduction (CPR) Mode

The PSL shall allow a calibrated output power reduction by remote command. The range of calibrated reduction shall be from full power (see Section 3.2.1.2) to 10 mW in steps no coarser than factors of three in power.

During operation in this mode, the power stabilization and frequency stabilization control loops shall remain locked and active, but with reduced performance requirements as described below.

3.2.1.15.4.1 PSL CPR Mode Power Fluctuations (from SYS)

During operation in CPR mode, the rms relative power fluctuations at the PSL output, measured with a 1 sec or greater integration time, shall be less than 1×10^{-3} .

3.2.1.15.4.2 PSL CPR Mode Frequency Fluctuations (from SYS)

During operation in CPR mode, the frequency fluctuations requirements at the PSL output shall be relaxed in proportion to the attenuation. For example, if the attenuation is a factor of 30, the frequency fluctuations may be 30 times greater than those required in normal operational mode.

3.2.1.16 PSL-Internal Diagnostics

The PSL shall incorporate all diagnostic sequences necessary to verify conformance with performance requirements. In some cases, e.g. frequency fluctuations requirements, the PSL might require signals from other detector subsystems in order to measure performance parameters. In such cases, the signal requirements shall be clearly detailed and communicated with the affected subsystem.

3.2.1.17 Availability

The PSL shall be designed to operate continuously without loss of 'lock' (even for short times) for 40 hours, during normal seismic conditions (90% percentile **TBD** by **SYS** for either site).

3.2.2. Physical Characteristics

3.2.3. Interface Definitions

3.2.3.1 Interfaces Between PSL and IOO

3.2.3.1.1 Mechanical Interfaces

3.2.3.1.1.1 Shared IOO/PSL Optical Table

PSL and the IOO share the IOO/PSL optical table. PSL has responsibility for the optical table and the optical table enclosure (to limit air currents, dust, thermal variations, acoustics, etc. The nominal requirements for the table enclosure are the same as the environmental requirements for the LVEA.) and IOO has responsibility for mounting it to (isolating it from) the LVEA foundation. The optical table design and performance are similar to that of the RS 4000™ table tops manufactured by Newport Corporation. The top surface of the table contains a pattern of 1/4"-20 tapped holes spaced at 1 in. intervals on a square grid. The table size is 5 ft. x 16 ft. x 24 in. thick. The space on the optical table shall be partitioned between the PSL and the IOO as shown in Figure 4, below.

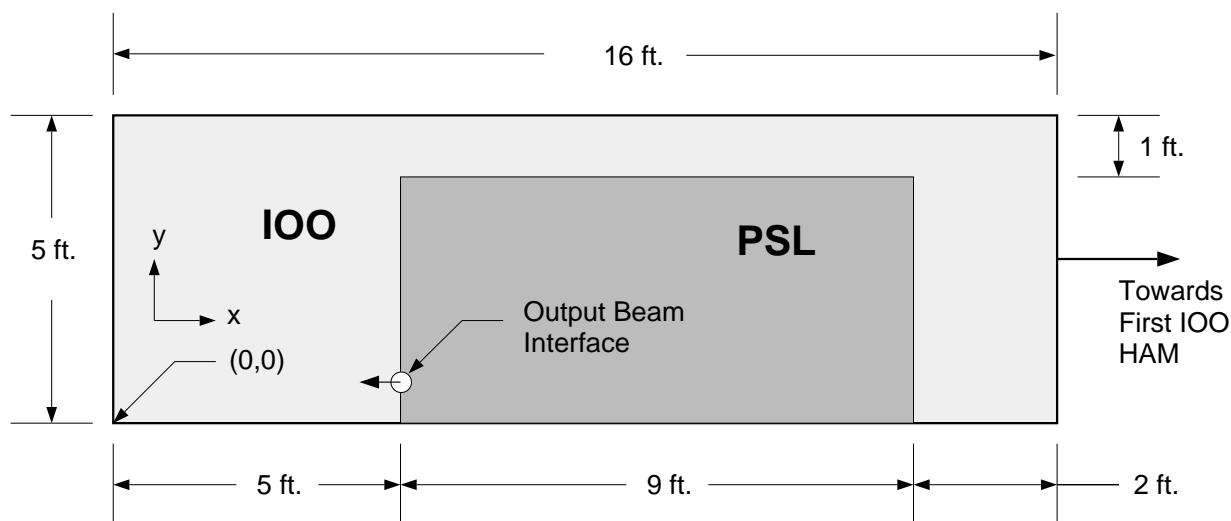


Figure 4: IOO/PSL optical table local coordinate system definition and IOO/PSL space partitioning.

3.2.3.1.1.2 Position of IOO/PSL Optical Table Inside LVEA

TBD by IOO/SYS

3.2.3.1.1.3 Distance from *IOO/PSL Optical Table Surface to LVEA Floor*

The height of the surface of the *IOO/PSL* optical table will be constrained by *IOO*'s requirements for the beam entering the adjacent HAM chamber and by the technique for mounting it to the LVEA floor along with the vibration isolation system employed, if any.

The distance from the *IOO/PSL* optical table surface to the LVEA floor shall be 89cm \pm 1.0 cm (**TBD** by *IOO/SYS*)

3.2.3.1.2 *Electrical Interfaces*

3.2.3.1.2.1 *PSL Wideband Frequency Control Input*

PSL shall provide a wideband frequency control input for frequency correction signals from the *IOO* mode cleaner servo¹. The interface parameters for the PSL Wideband Frequency Control Input are specified in Table 8.

<i>Parameter</i>	<i>Specification</i>
1. Signal Type	Analog
2. Signal Coupling	DC
3. Signal Range	± 15 V
4. Sensitivity	TBD Hz/V (by PSL)
Frequency response:	
Magnitude	
5. DC to 100 kHz	Flat within 2 dB
6. $f > 100$ kHz:	$< (f/100\text{kHz}) \times (\text{average response below } 100 \text{ kHz})$
7. Phase:	Phase lag at 100 kHz, $\phi < 20^\circ$

Table 8: Interface specifications for the PSL Wideband Frequency Control Input

3.2.3.1.3 *Optical Interfaces*

3.2.3.1.3.1 *PSL Output Beam Location*

The PSL output beam shall be delivered to the IOO at the location (72.5 in \pm 0.25in ,12.5 in \pm 0.25in) in the optical table local coordinate system defined in Figure 4. The optical height of the beam above the table surface shall be 4.75 in. \pm 0.1in .

1. Refer to LIGO-T970088-00-D, *Frequency Stabilization: Servo Configuration & Subsystem Interface Specification*

3.2.3.1.3.2 *PSL Output Beam Propagation Direction*

The beam propagation direction shall be parallel to the x axis in the optical table coordinate system and in the direction away from the first HAM chamber.

3.2.3.1.3.3 *PSL Output Beam Waist Size*

The spot size at the beam waist , w_0 , of the PSL output beam shall be 0.5 mm \pm 0.1 mm **TBD-IOO/SYS**.

3.2.3.1.3.4 *PSL Output Beam Waist Location*

The PSL output beam waist location shall be within 5.0 cm **TBD-IOO/SYS** of the PSL output beam location (refer to Section 3.2.3.1.3.1).

3.2.3.1.3.5 *Allowed Back-reflected light level from IOO*

The back-reflected light from the **IOO** toward the PSL shall be less than **TBD** by PSL/SYS Watts.

3.2.3.1.3.6 *Location of IOO/PSL Interface for Mode Cleaner Output Beam Sample for Power Stabilization*

The **IOO** output beam sample for power stabilization shall be delivered outside the vacuum vessel to the (**TBD-IOO/SYS**) optical table at the location (**TBD-IOO/SYS**)

3.2.3.1.3.7 *Power Level of IOO Output Beam Sample for Power Stabilization*

The power contained in the **IOO** output beam sample for power stabilization shall be greater than 25 mW (**TBD PSL/SYS**).

3.2.3.1.3.8 *Spot size of IOO Output Beam Sample for Power Stabilization*

At the IOO/PSL interface location (refer to Section 3.2.3.1.3.6), the spot size of the **IOO** output beam sample for power stabilization shall be 2.0 mm \pm 0.2 mm.

3.2.3.2 **Interfaces Between PSL and LSC**

3.2.3.2.1 *Electrical Interfaces*

3.2.3.2.1.1 *PSL Tidal Correction Frequency Control Input*

The PSL shall provide a very slow input for making the laser frequency track the common mode length changes of the interferometer's arms at tidal time scales. The interface parameters for the PSL Tidal Correction Frequency Control Input are specified in Table 9.

3.2.3.3 **Interfaces external to LIGO detector subsystems**

3.2.3.3.1 *Mechanical Interfaces*

3.2.3.3.1.1 *PSL/Facilities - Optical Table Vibration Isolators*

TBD by IOO/SYS

<i>Parameter</i>	<i>Specification</i>
1. Signal Type	Analog
2. Signal Coupling	DC
3. Signal Range	± 15 V
4. Sensitivity	TBD Hz/V (by PSL/SYS)
5. Frequency Response	Step response time constant < 1 hour
6. Control Range	± 30 MHz

Table 9: Interface Specifications for the PSL Tidal Correction Frequency Control Input

3.2.3.3.1.2 *PSL/Facilities - Laser Cooling Water Chiller Unit*

The laser cooling water chiller is located in the laser cooling water chiller enclosure which is located in the interstitial space between the LVEA inner and outer walls near the conduit stub ups for the cooling water hoses and control cables.

3.2.3.3.2 *Electrical Interfaces*

3.2.3.3.2.1 *PSL /Facilities - Power for Lightwave 10-W laser*

TBD by PSL

3.2.3.3.2.2 *PSL /Facilities - Power for Lightwave 10-W laser cooling water chiller unit*

TBD by PSL

3.2.3.3.2.3 *PSL /Facilities - Power for optical table enclosure*

TBD by PSL

3.2.3.3.3 *Stay Clear Zones*

3.2.3.3.3.1 *IOO/PSL Optical Table*

A stay clear zone of 42 in. width minimum shall be maintained on all sides of the **IOO/PSL** optical table enclosure. This stay clear zone provides space for the optical table enclosure as well as access to the table for maintenance and repairs.

3.2.3.3.3.2 *PSL Laser Cooling Water Chiller Unit*

A stay clear zone of 36 in. minimum is required in front of the laser chiller enclosure to facilitate maintenance and repairs.

3.2.4. Reliability

5,000 hours **TBD** by PSL/SYS Mean Time Between Failures (MTBF).

72 hours **TBD** by PSL/SYS Mean Down Time (MDT).

3.2.5. Maintainability**3.2.6. Environmental Conditions****3.2.6.1 Natural Environment***3.2.6.1.1 Temperature and Humidity**3.2.6.1.2 Atmospheric Pressure**3.2.6.1.3 Seismic Disturbance***3.2.6.2 Induced Environment***3.2.6.2.1 Electromagnetic Radiation*

All aspects of **PSL** shall be in conformance with specification LIGO-E960036-A-E, *LIGO EMI Control Plan And Procedures*.

*3.2.6.2.2 Acoustic**3.2.6.2.3 Mechanical Vibration***3.2.7. Transportability**

All items shall 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. All containers shall be movable for forklift. All items over 100 lbs. which must be moved into place within LIGO buildings shall have appropriate lifting eyes and mechanical strength to be lifted by cranes.

3.3. Design and Construction**3.3.1. Materials and Processes****3.3.1.1 Finishes****3.3.1.2 Materials****3.3.1.3 Processes****3.3.2. Component Naming**

All components shall identified as specified in *LIGO Naming Conventions*, LIGO E950111-A-E. This shall include identification physically on components, in all drawings and in all related documentation.

3.3.3. Workmanship

3.3.4. Interchangeability

3.3.5. 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 the LIGO Project System Safety Management Plan LIGO-M950046-F, section 3.3.2.

3.3.6. Human Engineering

3.4. Documentation

3.4.1. Specifications

3.4.2. Design Documents

3.4.3. Engineering Drawings and Associated Lists

3.4.4. Technical Manuals and Procedures

3.4.4.1 Procedures

Procedures shall be provided for, at minimum,

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

3.4.4.2 Manuals

3.4.5. Documentation Numbering

All documents shall be numbered and identified in accordance with the LIGO documentation control numbering system as described in LIGO Document Numbering Scheme, LIGO-L950003

3.4.6. Test Plans and Procedures

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

3.5. Logistics

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

3.6. Precedence

3.7. Qualification

4 QUALITY ASSURANCE PROVISIONS

4.1. General

4.1.1. Responsibility for Tests

4.1.2. Special Tests

4.1.2.1 Engineering Tests

4.1.2.2 Reliability Testing

Reliability evaluation/development tests shall be conducted on items with limited reliability history that will have a significant impact upon the operational availability of the system.

4.1.3. Configuration Management

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

4.2. 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:

4.2.1. Inspections

Inspection shall be used to determine conformity with requirements that are neither functional nor qualitative; for example, identification marks.

4.2.2. Analysis

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

4.2.3. Demonstration

Demonstration may be used for determination of qualitative properties and performance of an item and is accomplished by observation. Verification of an item by this method would be accomplished by using the item for the designated design purpose and would require no special test for final proof of performance.

4.2.4. Similarity

Similarity analysis may be used in lieu of tests when a determination can be made that an item is similar or identical in design to another item that has been previously certified to equivalent or more stringent criteria. Qualification by similarity is subject to Detector management approval.

4.2.5. Test

Test may be used for the determination of quantitative properties and performance of an item by technical means, such as, the use of external resources, such as voltmeters, recorders, and any test equipment necessary for measuring performance. Test equipment used shall be calibrated to the manufacturer's specifications and shall have a calibration sticker showing the current calibration status.

5 PREPARATION FOR DELIVERY

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

5.1. Preparation

Equipment shall be appropriately prepared. For example, vacuum components shall be prepared to prevent contamination.

5.2. Packaging

Procedures for packaging shall ensure cleaning, drying, and preservation methods adequate to prevent deterioration, appropriate protective wrapping, adequate package cushioning, and proper containers. Proper protection shall be provided for shipping loads and environmental stress during transportation, hauling and storage.

5.3. 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, stat-

utes, and common carriers; and all markings necessary for safety and safe delivery shall be provided.

6 NOTES