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-LIGO-
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Advanced-LIGO Optical Levers Design Requirements

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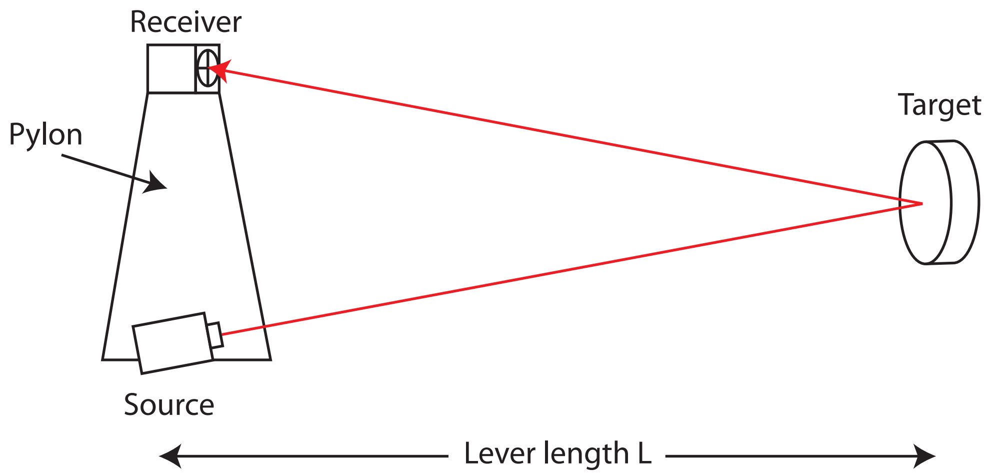

Figure 1: Baseline design for an optical lever, common to both advanced- and initial-LIGO.

1 Overview

This document establishes the design requirements for the advanced-LIGO optical lever subsystem.

2 Baseline design

For the purposes of calculation we will assume a baseline design similar to that of initial LIGO (see Figure 1), *i.e.* a low-power visible or near-infrared laser transmitted through a viewport and reflected from the surface of a suspended optic and sensed via a quad-cell photodetector.

3 Scope and objectives

3.1 Objectives

The optical-lever subsystem has the following objectives [1].

1. **Alignment fiducial:** The first goal is to assist in restoring alignment after invasive work. Optical levers may also be used to restore alignment after loss of lock, but only if such a requirement does not drive the system to an overly complex design.

2. **Optic drive tuning:** Optical levers will be used to tune the actuator drives on the optics to minimize position-to-angle coupling. They must be sensitive enough to do this to a level of 0.1 rad/m or better, given the drive level available, and in a reasonable time period.

3. **Local damping:** While the optlevs are not expected to be used for local damping in low-noise interferometer operation (as they are in iLIGO), we do want the ability to use them for such

damping during interferometer commissioning. For this, the optlev noise should be no worse than the iLIGO units, and welcome improvements would be higher frequency and/or better damped structural modes of the optlev supports.

4. **HAM Tables:** Monitor the angular alignment of the HAM optical tables.

3.2 Scope

As described in the “Baseline design” section, an optical lever unit consists of a laser transmitter, a receiver for measuring the lateral displacement of the beam, and associated optics and holding structures.

3.2.1 Inclusion

The optical-levers subsystem includes:

1. Source lasers, including fiber distribution system, if applicable.

2. All optics components required to control the optical-lever beam size and to position the beam on the optic or table being monitored, *except* the sensed optics and vacuum-feedthrough windows. If it is deemed necessary in the future to block stray light from the optical lever lasers, all necessary beam dumps - inside or outside the vacuum - will be included in the subsystem as well.

3. Quad photodetectors and the associated readout electronics to measure the lateral displacement of the optical-lever beam.

4. Structural pylons for mounting source and receiver hardware

3.2.2 Exclusion

The optical-lever subsystem expressly does *not* provide:

1. Servo systems, if any, to damp the angular motions of sensed optics

2. Initial alignment information.

3. Length sensing information.

3.2.3 Accessories

1. AR-coated viewports as necessary to allow optical access to the sensed optic

2. Cameras as needed for viewing the optical-lever beam to assist setup of the optical lever subsystem

4 Input to the design requirements

We had hoped, in the initial stages of setting the design requirements, that the optical levers could allow reacquisition of lock after a loss-of-lock event without the need for dither locking. The question of how much power buildup is required in each part of the interferometer for lock acquisition is, however, not well understood at the time of this writing. In the absence of a well-quantified physical model for lock acquisition as a function of power buildup, we decided to adopt the (seemingly) conservative requirement that the power in any one section of the interferometer be $1/e$ of its maximum value.

The assignment of optical levers is based on calculated alignment tolerances for the different suspended optics, the results of which are given in Table 1. These angles are the characteristic angles at which the power in the relevant cavity (arm, MICH, etc.) falls to $1/e$ of its full value, *i.e.*

$$\frac{P}{P_0} = e^{-(\theta/\Theta_X)^2}$$

where X represents the mirror in question, ITM, ETM, BS, etc. Table 1 lists Θ_X for all of the suspended optics. Derivation of these values is given in an appendix to this document.

5 Specific requirements

5.1 Interface

The optical lever subsystem shall provide the necessary signals to ISC to reacquire alignment during reacquisition of lock.

Electrical connections shall conform to the standards described in T060123-03, *Standard LIGO Electrical Interfaces,* by Richard Abbott [4].

5.2 Performance

5.2.1 Stability

All optical lever subsystems shall exhibit no more than

$$1.0\mu\text{Rad}$$

peak-to-peak pointing drift over timescales of minutes to hours, based on single-mirror misalignment calculations described in the appendix.

5.2.2 Noise

The optical levers shall impose no more than

$$4 \times 10^{-20} \frac{m}{\sqrt{Hz}} \left(\frac{10Hz}{f}\right)^2$$

Table 1: Misalignment tolerances, in μRad, for the different suspended optics. Optics with a 'Y' entry get optical levers. Throw is lever-arm distance in meters.

Optic	Straight	Folded	Lever	Throw (m)
ITM	2.6	2.5	Y	38.2
ETM	2.3	2.3	Y	5.7
ETM-H2	2.3	2.3	Y	3.3
BS	2.8	2.9	Y	2.1
PRM	157.0	142.0		
PR2	45.2	51.0		
PR3	2.7	2.8	Y	13.8
SRM	86.4	63.1		
SR2	18.6	58.6		
SR3	1.9	2.0	Y	14.4
SM1	305.0	TBD		
SM2	83.1	TBD		
PMMT1	136.9	TBD		
PMMT2	69.4	TBD		
MC1	125.0	TBD		
MC2	78.1	TBD		
MC3	125.0	TBD		
FMX	N/A	TBD	Y	1.9
FMY	N/A	TBD	Y	1.9
HAM2	N/A	N/A	Y	13.5
HAM3	N/A	N/A	Y	13.5
HAM4	N/A	N/A	Y	13.5
HAM5	N/A	N/A	Y	13.6
HAM8	N/A	N/A	Y	13.6
HAM9	N/A	N/A	Y	13.5
HAM10	N/A	N/A	Y	13.5
HAM11	N/A	N/A	Y	13.7

of displacement noise on the sensed optic, in science mode, at frequencies between 10 Hz and 10 kHz. One mechanism for such an imposition would be radiation-pressure noise. This requirement is based on the Science Requirement noise curve.

5.3 Physical

Optical lever beams shall monitor the angular orientation of the following optics in all interferometers: ITM (X and Y), ETM (X and Y), PR3, SR3, and the beamsplitter (BS). Additionally, optical levers shall monitor the angular orientation of both folding mirrors in the folded interferometer at Hanford. Optical levers shall also be placed on the in-vacuo optical tables in HAMs 2, 3, 4, 5, 8, 9, 10, and 11.

This requires a total of thirteen units each for H1 and L1, and fifteen for H2. In addition, at least three and preferably five additional units of each component will be produced for backup and diagnostic purposes.

All together, a minimum of forty-four (44) units shall be manufactured, with the preferred total being forty-six (46).

A stock of spares of each commonly-replaced component (e.g. laser diodes) shall be maintained at each site.

6 Documentation

Appropriate documentation shall be maintained at each site

7 Testing

A test plan shall be developed for verifying the specifications of the purchased components, in accordance with LIGO M050220-02, Guidelines for Advanced LIGO Detector Construction Activities.

7.1 Noise and stability performance

The advanced-LIGO optical lever subsystem shall be tested to verify that it's noise and stability are at least as good as, and whenever feasible better than, that of the initial-LIGO optical levers. Baseline performance of the initial-LIGO levers is described in Ref. [5] and [ref. Sam Waldman's, et al. noise v. frequency study, with the whitening filters Rana called our attention to].

7.2 OSEM interference

A quantitative measurement of the influence of the optical levers on the OSEMs, or at least an upper bound on it, shall be made and its influence on the interferometer performance evaluated.

8 Safety

It is preferred that each source operate at no more than 5 mW of total output power, so as to obviate any need for safety goggles or specialized enclosures for the beam.

All components 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 Safety Management Plan LIGO-M950046-F, Section 3.3.2.

References

[1] Peter Fritschel, private communication.

[2] Tipler, *Physics*, 2nd ed., p. 276.

[3] Mark Barton, private communication

[4] Richard Abbott, *Standard LIGO Electrical Interfaces,* T060123-03 (last updated November, 2008).

[5] Tara Chelermsongsak, Riccardo Desalvo, and Eric Black, *Optical Lever: Longterm test of the Laser Diode*, T1000157-v1 (last updated 25 March, 2010).