LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

- LIGO -

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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LIGO Detector Subsystem Review Report

DESIGN REQUIREMENTS REVIEW
Prestabilized Laser (PSL) & PSL Controls

Title

Review Board: A. Abramovici, W. Althouse (Chairman), J. Chapsky, A. Lazzarini, R. Spero, S. Whitcomb, M. Zucker

Author(s)

This is an internal working note of the LIGO Project

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REPORT ON THE DESIGN REQUIREMENTS REVIEW OF THE PRESTABILIZED LASER (PSL) AND PSL CONTROLS

Signature page

Review Board:

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W. Althouse, Chairman

J. Chapsky

A. Lazzarini

R. Spero

S. Whitcomb

M. Zucker

Accepted by:

R. Vogt
Detector Group Leader

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REPORT ON THE DESIGN REQUIREMENTS REVIEW OF THE PRESTABILIZED LASER (PSL) AND PSL CONTROLS

PARTICIPANTS:

Presenters

R. Bork, J. Camp, J. Heefner

Review Board

A. Abramovici, W. Althouse (Chairman), J. Chapsky, A. Lazzarini, R. Spero, S. Whitcomb, M. Zucker (via telephone).

Other attendees

B. Barish, L. Chu, D. Durance, P. Fritschel (telephone), D. Jungwirth, S. Kawamura, A. Kuhnert, L. Sievers, G. Sanders, V. Schmidt, D. Shoemaker (telephone), R. Vogt.

DOCUMENTS PRESENTED AND DISCUSSED:

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B. *Prestabilized laser controls*, J. Heefner, 1/30/95

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2. *Untitled*, J. Heefner
3. *PSL Software*, R. Bork
4. *PSL Implementation Aspects*, J. Heefner

REVIEW BOARD REPORT:

The review was conducted on February 6, 1995, in the LIGO Engineering Conference Room. The Review Board charge is included in this report as Attachment I. Summary presentations of the Design Requirements documents were given (see Agenda, Attachment II), followed by page-by-page review of the documents (submitted to the review board in advance). Responses to the Board charge and recommended action items arising during the presentations and document reviews are listed below.

- Is the list of identified requirements complete? Are the values appropriate?

The requirements identified in Reviewed Documents A and B (above) will be considered complete once the recommended analyses and additional or revised requirements listed in Action Items 1 through 8, and the recommended clarifications and additions listed in Action Items 11 and 12, are accomplished. The values provided need to be supported and/or supplemented by the

analyses and revision recommended in Action Items 2, 5, 7, 8, 11 and 12. These action items should be completed and results incorporated into the documents before re-submitting them for review at the PDRs.

- **Evaluate the conceptual design of the PSL/CDS and existing PSL/IFO subsystem for readiness for prototype fabrication and testing.**

Prototype fabrication and testing should be planned to accommodate the resolution of Action Items 3b, 4, 5, 8, 9 and 10. In particular, Action Item 10 should be completed before any modifications to the current PSL configuration are begun; Action Items 3b, 4, 5, and 8 should be completed before PSL/CDS prototype fabrication begins; Action Item 9 should be completed before the PSL PDR.

- **Recommend other appropriate actions.**

Other recommendations and PSL design suggestions are provided in Action Items 13 through 26.

RECOMMENDED ACTION ITEMS:

1. a. Provide a clear definition of scope of the PSL. The scope definition should explicitly identify all functional elements, especially those that interface to other subsystems (for example, does it include mode matching, optical table, dust enclosure, modulators for length sensing, optical spectrum analyzer, vacuum chamber and seismic isolation for the reference cavity?).

   b. Include the power stabilization photodetector in the scope of the PSL (instead of the input/output optics).

2. Perform and document a system-level analysis of the LIGO Detector and generate subsystem specifications (which become, e.g., requirements on the PSL subsystem). Specifically,

   2.1 Make an accurate shot noise calculation, including the effects of modulation and imperfect optics (based on the FFT model).

   2.2 The system specification for PSL laser power should be based on the shot noise calculation, taking care to separately account for noise from radiation pressure fluctuations.

   2.3 Revise the model for intensity noise coupling to include filtering due to recycling, up-conversion and down-conversion mechanisms, and amplitude noise at r.f. modulation frequency.

   2.4 Include beam quality and beam jitter specifications. Assess if there is a need for two mode cleaners in series.

   2.5 Analyze the combined effects of all noise sources, and specify what portion of the total noise budget is allocated to the PSL and other subsystems.

   2.6 Expand noise specifications to include drifts and transients.

3. a. Develop the general philosophy for diagnostics, and for implementing diagnostics in the PSL in particular (a broad group of people should be included).

   b. For the PSL, incorporate test inputs and monitors for all important functions including summing nodes for measuring loop gains; identify and include signal monitors and injection points (test inputs) required for commissioning and for testing operations linked to

other subsystems; provide for diagnostic measurement of cavity storage times; include an optical spectrum analyzer.

4. Include in the PSL design philosophy considerations of design economy, as opposed to uncritically adopting all features of the existing prototype. (For example, consider eliminating switched bypass amplification stage.)
5. Re-evaluate the choice of 10.7 MHz as a modulation frequency (note that this may become the subject of a system-wide evaluation, and may require phase-locking of subsystem modulation frequencies)
   - Choose and qualify a frequency which is interference-free and which does not restrict frequencies used for length control.
   - Establish a preference for designs that accommodate a range of frequencies.
6. Substitute the concept of "availability" for "duty cycle," and analyze the availability of the PSL, with an eye toward increasing the availability to better than 95%. Include considerations of fast laser servicing, as may be achieved by a backup laser system
7. Evaluate loss due to the intensity power stabilizer and include in power loss budget.
8. Perform an analysis to determine electronic noise limits placed on photodiodes and amplifiers.
9. Develop a plan for beam jitter tests.
10. Document the performance of the current prestabilized laser configuration to serve as a baseline reference for the planned PSL prototype, before any configuration changes are implemented.
11. Incorporate the following clarifications and additions into the document, *Prestabilized Laser IFO Design Requirements*:
    - 11.1 Clarify the distinction between requirements and baseline specifications.
    - 11.2 Terminology change: substitute for "IFO" "optical and mechanical parts of the PSL," or similar.
    - 11.3 All figures and tables should be numbered and captioned.
    - 11.4 All references to documents should be explicit, with working papers numbered (or marked "Document Number TBD").
    - 11.5 Use symbols to denote shot-noise limited sensitivity, intensity noise (a coefficient to the formula), and availability.
    - 11.6 Explicitly include the following factors in the frequency noise requirement (and use symbols for each):
      - Safety margin.
      - Common-mode suppression due to matching of arm cavity storage times
      - Suppression from measuring residual frequency noise after high-gain stabilization, and subtracting residual from interferometer output signal.
      - Filtering due to recycling cavity.
    - 11.7 Noise levels should be specified in amplitude spectral density units (for example, strain/rHz)
    - 11.8 Clarify the phrase "with the light," for example by substituting "with respect to the

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11.9 Include specifications for the quality of the cooling water, and a tolerance on the cooling water temperature.

11.10 Reexamine the tolerance on the laboratory temperature control.

11.11 Substitute "a supply of clean dry nitrogen" for "a nitrogen cylinder."

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11.17 Clarify the specifications and conclusions about polarization noise.

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11.19 The beam height should be called out (probably as TBD), as should the optical table environment and similar interface-specific specifications.

11.20 Interfaces should be made more specific, categorized (such as optical, mechanical, signal), and clearly distinguished from conceptual design material.

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12.4 Include effects of electronics on facility, such as acoustic noise and EMI generation.

12.5 Terminology: distinguish between "sensor" and "actuator."

12.6 Re-evaluate the parameters for the ringdown measurements, given the expected cavity storage times.

12.7 Make the distinction between "update rate" and "reaction time" explicit.

12.8 Change the power supply voltage for PZT steering mirrors to +100 V.

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- Add "RF Photodiode Monitor," and consider adding cavity ringdown signals.
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12.23 Table 29: Add alarms for PZT voltages near end of range.

OTHER RECOMMENDATIONS:

Global considerations:

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14. Prepare a memo with guidelines on the use of English and metric units.

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16. Establish standards and guidelines for design. Applied to global CDS design, standards should be established for wiring, connections, packaging, and documentation.

17. For future document reviews, parcel assignments to individuals based on subsections.

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19. Establish a group to identify existing knowledge on performance of PSL circuits, with the charge of writing a report that identifies problems.

Suggestions Specific to the Prestabilized Laser:

20. Consider effects of ambient acoustic and vibration noise on frequency noise performance; determine whether additional local isolation of the laser table is needed or desirable.
21. Consider monitor and control of the driver for the Acousto Optic Modulator, including a frequency-counter monitor.
22. Consider adding an etalon temperature monitor.
23. Consider monitoring current output of power supplies.
24. Consider changing the purge gas pressure monitor to a flow monitor.
25. Consider the requirements of other subsystems with common functionality in choosing implementation parameters. For example, the phase shifters used for length sensing will likely require finer adjustment steps.
26. Consider deriving the local oscillator reference from the output side of the matching network.

CALIFORNIA INSTITUTE OF TECHNOLOGY

Laser Interferometer Gravitational Wave Observatory (LIGO) Project

To/Mail Code: Distribution
From/Mail Code: R. Vogt/ 102-33
Phone/FAX: 395-3800/304-9834
Refer to: LIGO-L9500 31
Date: January 27, 1995

Subject: PSL DRR

The Design Requirements Review (DRR) for the LIGO Detector Prestabilized Laser (PSL) subsystem will be held on Monday, February 6, 1995, in the Engineering Conference Room (Rm. 39 Bridge Annex), beginning at 9:00 a.m. The review board will consist of:

A. Abramovici
W. Althouse (Chairman)
J. Chapsky
A. Lazzarini
R. Spero
S. Whitcomb
M. Zucker (via telecon)

REVIEW BOARD CHARGE:

1) Determine whether the requirements identified in the Design Requirements Documents are complete; advise whether proposed requirement values are appropriate; if needed, recommend additional requirements to be specified; and recommend other appropriate actions.

2) Evaluate the conceptual design of the PSL/CDS system and review the existing PSL/IFO system for readiness for the planned fabrication and testing as a prototype.

The review meeting is expected to last through early afternoon. Interested members of the LIGO technical and management staff are invited to attend (MIT personnel by telecon). Copies of the PSL Design Requirements Documents and agenda will be furnished to review board members Monday, 1/30/95.

RV/bb

PRESTABILIZED LASER (PSL) SYSTEM

Design Requirements Review

Monday, February 6, 1995
9:00 am
LIGO ECR

AGENDA

A) Scope and Purpose (JC - 10 min)

- Scope of the DRR
- Purpose of the DRR
- Organization of the presentation

B) PSL System Requirements and PSL IFO Conceptual Design
(JC - 80 min)

- LIGO primary requirements
- PSL design requirements (power, frequency noise, intensity noise, beam jitter, duty cycle)
- PSL IFO conceptual design
- facility requirements
- PSL prototype testing

C) Discussion - PSL IFO Design Requirements Document

D) PSL Controls Requirements and HW Conceptual Design (JH 90 min)

- Scope
- Purpose
- list of major TBD's
- CDS CIM model
- interfaces
- VME/VXI
- per local control unit (LCU)
  -- location in CIM model
  -- requirements
  -- conceptual design
    --- Laser LCU
    --- Phase Modulation LCU
    --- Power (Intensity) Stabilization LCU
    --- Frequency Stabilization LCU
    --- Laser Steering LCU
- PSL subsystem requirements and conceptual design

E) Discussion - PSL CDS Design Requirements Document

F) PSL Controls SW (RB 60 min)

- SW Development Plan
- Tools and Platforms
- Computer System Overview
- Software System Architecure
- SW CIM model
- PSL SW Applications
- Example: Laser Slow PZT Scan Sequence
- Protoype Operator Displays
- Device Drivers and Devices

G) PSL implementation (JC 20 min)

- space and power requirements
- schedule
- risk analysis

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To/Mail Code: Distribution
From/Mail Code: R. Vogt/ 102-33
Phone/FAX: 395-3800/304-9834
Refer to: LIGO-L9500 31
Date: January 27, 1995

Subject: PSL DRR

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1) Determine whether the requirements identified in the Design Requirements Documents are complete; advise whether proposed requirement values are appropriate; if needed, recommend additional requirements to be specified; and recommend other appropriate actions.

2) Evaluate the conceptual design of the PSL/CDS system and review the existing PSL/IFO system for readiness for the planned fabrication and testing as a prototype.

The review meeting is expected to last through early afternoon. Interested members of the LIGO technical and management staff are invited to attend (MIT personnel by telecon). Copies of the PSL Design Requirements Documents and agenda will be furnished to review board members Monday, 1/30/95.

RV/bb

PRESTABILIZED LASER (PSL) SYSTEM

Design Requirements Review

Monday, February 6, 1995
9:00 am
LIGO ECR

AGENDA

A) Scope and Purpose (JC - 10 min)

- Scope of the DRR
- Purpose of the DRR
- Organization of the presentation

B) PSL System Requirements and PSL IFO Conceptual Design
(JC - 80 min)

- LIGO primary requirements
- PSL design requirements (power, frequency noise, intensity noise, beam jitter, duty cycle)
- PSL IFO conceptual design
- facility requirements
- PSL prototype testing

C) Discussion - PSL IFO Design Requirements Document

D) PSL Controls Requirements and HW Conceptual Design (JH 90 min)

- Scope
- Purpose
- list of major TBD's
- CDS CIM model
- interfaces
- VME/VXI
- per local control unit (LCU)
  -- location in CIM model
  -- requirements
  -- conceptual design
    --- Laser LCU
    --- Phase Modulation LCU
    --- Power (Intensity) Stabilization LCU
    --- Frequency Stabilization LCU
    --- Laser Steering LCU
- PSL subsystem requirements and conceptual design

E) Discussion - PSL CDS Design Requirements Document

F) PSL Controls SW (RB 60 min)

- SW Development Plan
- Tools and Platforms
- Computer System Overview
- Software System Architecure
- SW CIM model
- PSL SW Applications
- Example: Laser Slow PZT Scan Sequence
- Protoype Operator Displays
- Device Drivers and Devices

G) PSL implementation (JC 20 min)

- space and power requirements
- schedule
- risk analysis