**Exhibit B: Requirements Document**
**to**
**AURA Contract No. 0084699-GEM00417**

# Requirements for the Gemini South and Keck I Laser Systems

**Prepared By: Céline d'Orgeville, Mike Sheehan, Peter Wizinowich, Jason Chin, Sean Adkins, Robert Lafon**

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**Version: V2.91**

**Table of Contents**

**Table of Contents**

**Table of Contents**

**Table of Contents**

## Figures and Tables

# 1 INTRODUCTION

The Association of Universities for Research in Astronomy (AURA), operators of the Gemini Observatories, and the California Association for Research in Astronomy (CARA), operators of the W. M. Keck Observatory (WMKO) wish to obtain lasers for optical excitation of the mesospheric sodium layer to enable the production of artificial beacon sources or "guidestars". Guidestars are used to permit improved operation of adaptive optical systems on astronomical telescopes.

AURA wishes to procure two lasers, one for the Gemini South Observatory (GS) and one for the Keck I telescope LGS facility at WMKO. Gemini and WMKO have jointly developed this document to establish requirements for these two laser systems.

## 1.1 Scope and Applicability

This requirements document is for the laser system component of the GS laser guide star (LGS) facility and the Keck I LGS facility. The GS LGS facility will be operated at the Gemini South telescope located at the summit of Cerro Pachón, Chile, at an altitude of approximately 2,700 m. The Keck I LGS facility will be operated at the Keck I telescope located at the summit of Mauna Kea, Hawaii, at an altitude of approximately 4,200 m. Except as noted otherwise the requirements listed in this requirements document are common to both the Gemini South laser system and the Keck I laser systems.

## 1.2 Revision History

| Revision | Date | Author (s) | Reason for revision / remarks |
|---|---|---|---|
| 1.0 | April 8, 2005 | CDO | Initial release |
| 1.1 | April 13, 2005 | AF, MS | |
| 2.0 | May 16, 2005 | CDO, MS, PW, JC | Combine Gemini South and Keck I laser systems requirements in this document |
| 2.1 | May 17, 2005 | AF | |
| 2.2 | May 23, 2005 | DS | |
| 2.3 | May 31, 2005 | SMA | Added WMKO requirements, edits for clarity and content |
| 2.4 | June 2, 2005 | SMA | Completed editing of sections 5.7 and following |
| 2.5 | June 7, 2005 | CDO, MS | |
| 2.55 | June 8, 2005 | SMA | Further edits |
| 2.60 | June 9, 2005 | SMA, CDO, MS | Final clean up edits |
| 2.61 | June 9, 2005 | SMA | Second release |
| 2.70 | July 26, 2005 | MS, CDO, SMA | Further revisions prior to contract release |
| 2.71 | July 27,2005 | SMA | Added requirement REQ-LS-0879 |
| 2.8 | August 3, 2005 | CDO | Edited performance requirements section and reviewed/edited remainder of the document |
| 2.81 | August 4, 2005 | SMA | Third release |
| 2.82 | August 5, 2005 | SMA | Fourth release, minor corrections, added Keck I vibration curve |
| 2.90 | August 22, 2005 | SMA | Final release based on CTI/Gemini/WMKO telecon |
| 2.91 | August 23, 2005 | SMA | Minor corrections to the final release, this version now final |

In version 1.1 the GS laser system was described as being preferably mounted on the GS telescope center section at the same location used to mount the Gemini North (GN) laser system on the GN telescope. In subsequent revisions AURA is now considering alternative mounting locations for the GS laser system.

### 1.3 Format

This document is divided into 9 major sections:

- References
- Performance Requirements
- Operational Requirements
- Functional Requirements
- Reliability Requirements
- Spares Requirements
- Service and Maintenance Requirements
- Documentation Requirements
- Appendices

Acronyms and abbreviations used throughout this document are defined in §2.5.

### 1.4 Requirements

Throughout this document a unique number in the form "REQ-LS-XXXX" for ease of reference usually identifies requirements. However, the absence of such a number shall not be construed as meaning that something is not a requirement if it otherwise appears to be mandatory. In all documentation discussing the Gemini South and Keck I laser systems requirements, the vendor shall always reference the requirements by the number assigned herein. An index to the requirement numbers may be found starting on page 73 of this document.

The laser systems provided by the vendor must meet all requirements given in this document.

### 1.5 Goals

This document also establishes various goals to set the target for achievement of performance or the provision of additional features and functions. Items specifically identified as "goals" are not requirements that must be met by the laser systems. The vendor will attempt to meet or partially meet the goal if it can be designed in at no additional cost. The word **goal** is usually in boldface to help differentiate goals from requirements.

# 2 REFERENCES

## 2.1 Referenced Documents

Documents referenced in the requirements are listed in Table 1. Copies of these documents may be obtained from the source listed in the table.

| Ref. # | Document # | Revision or Effective Date | Source | Title |
|---|---|---|---|---|
| 1 | ICD 1.14.9/1.1.1 | D | Gemini | Gemini South Laser System to the Telescope Structure Interface Control Document |
| 2 | ICD 1.14.9/1.13.3 | E | Gemini | Gemini South Laser System to the Beam Transfer Optics Interface Control Document |
| 3 | ICD 1.1.13/1.14.9 | B | Gemini | Gemini Laser Interlock System to Gemini South Laser System Interface Control Document |
| 4 | ICD 1.1.13/1.13.1 | G | Gemini | Gemini Laser Interlock System to Gemini North Laser System Interface Control Document |
| 5 | N/A | N/A | Gemini | MCAO Command Client/Server Interface Definition Document |
| 6 | N/A | N/A | | This reference deleted. |
| 7 | N/A | N/A | | This reference deleted. |
| 8 | N/A | N/A | | This reference deleted |
| 9 | ICD 1.13.1/1.13.14 | E | Gemini | Gemini North Laser to Gemini North Laser EPICS Interface |
| 10 | N/A | N/A | Keck | Keck I Laser System to the Telescope Structure Interface Control Document |
| 11 | N/A | N/A | Keck | Keck I Laser System to the Keck I Beam Transfer Optics Interface Control Document |
| 12 | 1MV0000005A | A | CTI | Requirements Specification – Structural Analysis and Verification Practices |
| 13 | 1FP0000001 | - | CTI | MiDAS Coding Standard |
| 14 | N/A | N/A | CTI | Variable Naming Guidelines |

**Table 1: Referenced Documents**

## 2.2 Referenced Standards

Table 2 lists the standards documents referenced in this requirements document. Standards are listed in alphabetical order by standardizing organization. Unless otherwise noted all references to standards are included because compliance with some part of each standard may be required.

| Source (Organization or Standardizing Body) | Number | Title |
|---|---|---|
| ANSI | Y14.5M-1994 (R1999) | Dimensioning and Tolerancing |
| ANSI | Y14.1-1995 (R2002) | Decimal Inch Drawing Sheet Size And Format |
| ANSI | Y14.34-2003 | Parts Lists, Data Lists, And Index Lists: Associated Lists |
| ANSI | Y14.3M-1994 | Multi And Sectional View Drawings |
| ANSI | ANSI/VITA 1-1994 (R2002) | VME64 |
| ANSI | ANSI/VITA 1.1-1997 (R2003) | VME64 Extensions |
| ANSI | Z136.1-2000 | American National Standard for the Safe Use of Lasers |
| ANSI / ASME | Y14.18M-1986 | Optical Parts (Engineering Drawings and Related Documentation Practices) |
| ASME | Y14.100-2000 | Engineering Drawing Practices |
| ASME | Y32.10-1967 (R1994) | Graphic Symbols for Fluid Power Diagrams |
| ATA | Spec 300-2001.1[1] | Specification for Packaging of Airline Supplies |
| County of Hawaii | 1995 edition[1] | Hawaii County Code 1983 (1995 edition) |
| Department of Defense | MIL-STD-171E | Finishing of Metal and Wood Surfaces |
| | | |
| Department of Defense | MIL-HDBK-454A | General Guidelines for Electronic Equipment |
| Department of Defense | MIL-STD-461E | Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment |
| Department of Defense | MIL-STD-464 | Electromagnetic Environmental Effects, Requirements for Systems |
| Department of Defense | MIL-STD-810F | Test Method Standard for Environmental Engineering Considerations and Laboratory Tests |
| Department of Defense | MIL-HDBK-1857 | Grounding, Bonding and Shielding Design Practices |
| Food and Drug Administration | CFR 21 Part 1040, April 1, 2004 | Performance Standards for Light-Emitting Products |
| IEEE | 802.3U revision 95 | Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications: Mac Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mb/S Operation (Version 5.0) |
| IEEE | 1012-2004 | Standard for Software Verification and Validation |
| International Code Council (ICC) | IBC-2003 | 2003 International Building Code |
| NFPA | 2005 edition | National Electric Code |

1. Informative reference.

**Table 2: Referenced Standards**

| Source (Organization or Standardizing Body) | Number | Title |
|---|---|---|
| OSHA | Title 29 CFR Part 1910 | Occupational Safety And Health Standards |
| OSHA | STD 01-05-001 | Guidelines for Laser Safety and Hazard Assessment |
| Telcordia | GR-63-CORE | NEBS™ Requirements |

1. Informative reference.

**Table 2: Referenced Standards, continued**

### 2.3 Referenced Drawings

Documents referenced in the requirements are listed in Table 3. Copies of these documents may be obtained from the source listed in the table.

| Drawing # | Revision/Date | Source | Title |
|---|---|---|---|
| 110-10-07 | C/6-12-03 | WMKO | Keck I Telescope Travel Limits |
| 90-GP-0001-0016 | B | Gemini | Telescope Overview (f/16 Top End) |
| 89-GP-3110-0010 | D | Gemini | GS Laser Bench Enclosure Outline and Laser Output Beam Geometry |
| 89-GP-3110-0011 | C | Gemini | GS Laser System to Telescope Interface |
| 1750-C3000 | A | WMKO | Keck I Laser Service Enclosure Location |
| 1750-C3001 | A | WMKO | Keck I Laser System Envelope |
| 1750-C3002 | TBD | WMKO | Keck I Laser System to BTO Interface |

**Table 3: Referenced Drawings**

### 2.4 Interface Cross Reference

The GS and Keck I laser systems have multiple interfaces with the GS and Keck I telescopes in general and with subsystems of the GS and Keck I AO systems in particular. To enhance commonality between the GN LGS facility, the GS LGS facility and the Keck I LGS facility infrastructures, most of the interface requirements presented in this document have been derived from interfaces designed and developed in the context of the Gemini North LGS facility. A notable exception to this comes from the fact that the GS laser system must deliver *five* laser beams to the GS BTO whereas the GN laser system and Keck I laser system only deliver a *single* beam to their respective BTOs.

Interfaces of the GS and Keck I laser systems with other Gemini and WMKO systems are summarized in Table 4. Please refer to the sections indicated in that table for the corresponding interface requirements.

| | **Laser System Interfaces** | | | |
|---|---|---|---|---|
| **Gemini and Keck Systems** | **Optical Interface** | **Mechanical Interface** | **Electronic Interface** | **Software Interface** |
| Telescope | N/A | 3.2.1.4<br>3.2.2.3<br>5.3.1.2<br>5.8.1.1 | 3.3.1.1<br>5.3.13<br>5.6.5.2 | N/A |
| BTO | 3.1.2.3 | 5.8.1.2 | N/A | N/A |
| LEI | N/A | N/A | 5.4.1.9.4 | 5.7.5.1 |
| LIS | N/A | N/A | 5.6.4.2 | N/A |

**Table 4: Interfaces between the GS and KI Laser System and other Gemini and Keck systems**

## 2.5 Acronyms and Abbreviations

Table 5 defines the acronyms and abbreviations used in this document.

| Acronym/Abbreviation | Definition |
|---|---|
| abs(x) | Absolute value function of the variable x, such that abs(x) = +x if x≥0, and abs(x) = -x if x≤0 |
| ANSI | American National Standards Institute |
| AO | Adaptive Optics |
| AOM | Adaptive Optics Module |
| ASME | American Society of Mechanical Engineers International |
| ATA | Air Transport Association |
| AURA | Association of Universities for Research in Astronomy |
| avg(x,T) | Average function of the variable x over a time period T |
| BDM | Beam Dump Mirror |
| BTO | Beam Transfer Optics |
| CARA | California Association for Research in Astronomy |
| CC | Component Controller |
| CCD | Charge Coupled Device |
| CDRH | Center for Devices and Radiological Health |
| CENELEC | European Committee for Electrotechnical Standardization |
| CFR | Code of Federal Regulations |
| COTS | Commercial Off-The-Shelf |
| CP | Cerro Pachón |
| CSI | Command and Status Interface |
| CW | Continuous Wave |
| CW ML | Continuous Wave Mode-Locked |
| dBA | Sound level in decibels, measured using the A contour frequency weighting network |
| DHS | Data Handling System |
| DM | Deformable Mirror |
| EE | Encircled Energy |
| EIA | Electronic Industries Alliance |
| EMI | Electro Magnetic Interference |
| EPICS | Experimental Physics and Industrial Control System |
| FDA | Food and Drug Administration |
| FF | Far Field |
| FOV | Field Of View |
| FWHM | Full Width at Half Maximum. The width across an optical beam or frequency profile where its intensity drops to half of its peak, or maximum, value. Unless otherwise indicated for optical beams the beam is assumed to be symmetric about the optical axis. |
| GIS | Gemini Interlock System |
| GN | Gemini North |
| GS | Gemini South |
| GSAO | Gemini South Adaptive Optics |
| GSAO CS | Gemini South Adaptive Optics Control System |
| GUI | Graphical User Interface |
| IBC | International Building Code |
| ICC | International Code Council |
| ICD | Interface Control Document |
| IEEE | Institute of Electrical and Electronics Engineers |
| KSD | Keck Software Document |

**Table 5: Acronyms and Abbreviations**

| Acronym/Abbreviation | Definition |
|---|---|
| LAN | Local Area Network |
| LCS | Laser Control System |
| LEI | Laser EPICS Interface |
| LGS | Laser Guide Star |
| LGS AO | Laser Guide Star Adaptive Optics |
| LIS | Laser Interlock System |
| LLT | Laser Launch Telescope |
| LS | Laser System |
| MCAO | Multi-Conjugate Adaptive Optics |
| MK | Mauna Kea |
| ML | Mode-Locked |
| MM | Coherent Inc. ModeMaster PC |
| MTTR | Mean Time To Repair |
| N/A | Not Applicable |
| NA | Numerical Aperture |
| NEBS | Network Equipment Building System |
| NEMA | National Electric Manufacturers Association |
| NF | Near Field |
| NFPA | National Fire Protection Association |
| NGS | Natural Guide Star |
| OCS | Observatory Control System |
| OSHA | Occupational Safety and Health Administration |
| PCI | Peripheral Component Interface |
| PRF | Pulse Repetition Frequency |
| PSD | Power Spectrum Density |
| REQ-LS-XXXX | Requirement for the Gemini South and Keck I Laser Systems |
| RFP | Request For Proposals |
| RH | Relative Humidity |
| rms | root-mean-square |
| rms(x,T) | Standard deviation function of the variable x over a time period T, such that rms(x,T) = sqrt(avg(x^2,T) - [avg(x,T)]^2,T) |
| RTC | Real Time Controller |
| RTD | Resistance Temperature Detector |
| SALSA | Safe Aircraft Localization and Satellite Acquisition system |
| SC | Supervisory Controller |
| TBC | To Be Completed |
| TBD | To Be Determined |
| TBS | To Be Specified |
| TCS | Telescope Control System |
| TTL | Transistor-Transistor Logic |
| UPS | Uninterruptible Power Supply |
| UL | Underwriters Laboratories Inc. |
| USGS | United States Geological Survey |
| Vac | Voltage alternating current |
| Vdc | Voltage direct current |
| VME | VerasaModule Eurocard |
| WFS | Wavefront Sensor |
| WMKO | W. M. Keck Observatory |

**Table 5: Acronyms and Abbreviations, continued**

# 3 PERFORMANCE REQUIREMENTS

## 3.1 Optical

### 3.1.1 Parametric Performance Requirements

Parametric optical performance requirements for the laser system are given in Table 6. Unless noted otherwise all requirements apply to the output beam or beams of the laser system and are to be measured at the laser system output aperture.

| *Parameter* | *Requirement Number* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|---|
| Total Power | | | | | | |
| GS | REQ-LS-0100 | 50 | - | - | W | 1 |
| Keck I | REQ-LS-0101 | 20 | - | - | W | 1 |
| Power non-uniformity | | | | | | |
| GS | REQ-LS-0110 | - | - | 10 | % | 2 |
| Power stability | | | | | | |
| Short term | REQ-LS-0115 | - | - | 10 | % | 3 |
| Long term | REQ-LS-0116 | - | - | 5 | % | 4 |
| Power levels | | | | | | |
| Full power | REQ-LS-0130 | 100 | - | - | % | 5,6,7 |
| Low power | | | | | | |
| GS | REQ-LS-0131 | - | - | 0.1 | W | 6,7 |
| Keck I | REQ-LS-0132 | - | - | 0.1 | W | 6 |
| Spectral characteristics | | | | | | |
| Nominal central wavelength | REQ-LS-0135 | - | 589.0 | - | nm | 8 |
| Central frequency stability | REQ-LS-0140 | - | - | 100 | MHz | 9 |
| Spectral bandwidth | REQ-LS-0145 | - | 1.0 | 1.5 | GHz | 10 |
| Out of band power | REQ-LS-0120 | - | - | 0.1 | W | |
| Tunability | | | | | | |
| Central freq. step size | REQ-LS-0150 | - | - | 100 | MHz | |
| Central freq. step range | REQ-LS-0151 | -300 | | +300 | MHz | 11 |
| Central freq. shift size | REQ-LS-0155 | 5 | - | 20 | GHz | 12 |
| Central freq. shift time | REQ-LS-0160 | - | - | 30 | s | 13 |
| Beam diameter | | | | | | |
| GS | REQ-LS-0195 | 4.70 | 5.0 | 5.30 | mm | 14,15 |
| Keck I | REQ-LS-0196 | 4.70 | 5.0 | 5.30 | mm | 14,15 |
| Output aperture | | | | | | |
| Power loss | REQ-LS-0200 | - | - | 0.5 | % | 16 |
| Far-field loss | REQ-LS-0201 | - | - | 1.0 | % | 17 |
| Beam quality | | | | | | |
| $M^2$ | REQ-LS-0205 | 1.0 | - | 1.4 | | 14,18 |
| Stability | REQ-LS-0210 | - | - | 10 | % | 19 |
| Pointing stability | | | | | | |
| Transverse | REQ-LS-0215 | -0.5 | - | 0.5 | mm | 14,20 |
| Angular | | | | | | |
| Long term | REQ-LS-0220 | -0.4 | | 0.4 | mrad | 14,21 |
| Short term | REQ-LS-0225 | | | 20 | µrad | 14,22 |
| Linear polarization ratio | REQ-LS-0240 | 0.95 | - | - | :1 | 23 |

**Table 6: Optical Performance Requirements**

Notes to Table 6:

1. Absolute minimum power in watts at 589.0 nm at the highest peak of the sodium D2 line within an aperture of a diameter no smaller than the 99% encircled energy diameter of the laser beam.
2. ~~Power variation in % peak to peak among the 5 output beams of the GS system over a 12 hour period defined as follows:~~
   ~~$P(i)_t$ = The measured average power of any output laser beam (i) at any time t over the period [t-1.25 ms, t]~~
   ~~(This corresponds to measurements made at an 800 Hz sampling rate with 1.25 ms long samples.)~~
   ~~For any two beams (i) and (j), at any time t in a 12 hour period (T):~~
   ~~$abs(P(i)_t - P(j)_t) < 0.1*(avg(P(i)_t,T)$, and~~
   ~~$abs(P(i)_t - P(j)_t) < 0.1*(avg(P(j)_t,T)$~~
   ~~(This corresponds to a 10% peak to peak variation over 12 hours at an 800 Hz sampling rate with 1.25 ms long samples.) This requirement can be proven by design only if all five output beams are generated from a single 589 nm beam.~~
2. *This note deleted.*
3. Power fluctuation in % peak to peak over a 5 minute period, defined as follows:
   $P(i)_t$ = The measured average power of any output laser beam (i) at any time t over the period [t-1.25 ms, t]
   (This corresponds to measurements made at an 800 Hz sampling rate with 1.25 ms long samples.)
   For any times t, t1 and t2 within a period T = 5 minutes, i.e. $0 < t, t1, t2 < T$:
   $abs(P(i)_{t2} - P(i)_{t1}) < 0.05*avg(P(i)_t,T)$
   (This corresponds to a short term power stability requirement of less than 10% peak to peak over 5 minutes at an 800 Hz sampling rate with 1.25 ms long samples.)
4. Power fluctuation in % rms over a 12 hour period, defined as follows:
   $P(i)_t$ = The measured average power of any output laser beam (i) at any time t over the period [t-1.25 ms, t]
   (This corresponds to measurements made at an 800 Hz sampling rate with 1.25 ms long samples.)
   For any time t within a period T = 12 hours, i.e. $0 < t < T$:
   $rms(P(i)_t,T) < 0.05*avg(P(i)_t,T)$
   (This corresponds to a long term power stability requirement of less than 5% rms over 12 hours at an 800 Hz sampling rate with 1.25 ms long samples.)
5. Full power level shall correspond to 100% of the required laser system total output power.
6. Laser system shall provide two power settings; one called "FULL POWER" mode and one called "LOW POWER" mode. For the GS laser system power setting shall be applied simultaneously to all 5 output beams.
7. Per beam.
8. The nominal central wavelength shall correspond to the highest peak of the sodium D2 line as shown in appendix A (Figure 3).
9. With respect to the nominal central wavelength over a 12 hour period, defined as follows:
   $f_0$ = The frequency of the highest peak of the sodium D2 line as shown in appendix A (Figure 3)
   $f(i)_t$ = The measured central frequency of any output beam (i) at any time t over a period [t-200 ms, t]
   (This corresponds to measurements made at an 5 Hz sampling rate with 200 ms long samples.)
   For any time t within a period T = 12 hours, i.e. $0 < t < T$:
   $abs(f(i)_t - f_0) < 100$ MHz
   (This corresponds to a central frequency stability requirement of less than ±100 MHz over a 12 hour period at an 5 Hz sampling frequency with 200 ms long samples.)
10. At the FWHM of the spectral bandwidth curve.

11. With respect to the nominal central frequency.
12. The laser system shall provide at least one tuning shift either side of the nominal central frequency. At all times the laser output power shall continue to meet REQ-LS-115 and REQ-LS-116. For the GS laser system the tuning shift shall be applied simultaneously to all 5 output beams.
13. Time for one shift away from and back to the central frequency.
14. In the plane of the laser system output aperture.
15. At the $1/e^2$ intensity points.
16. Maximum total output power loss through the output aperture. Compliance will be demonstrated by design.
17. Maximum far-field intensity reduction for the central lobe. Compliance will be demonstrated by design.
18. Over periods of $\geq 1$ s.
19. Maximum variation in the percentage of the $M^2$ value between two consecutive measurements made at the fastest measurement update rate available from the beam diagnostics measurement facility described in section 4.1.2, with the agreement that 1 measurement out of every 20 may be discarded.
20. Peak to peak variation in the transverse position of the output beam.
21. Maximum peak to peak variation in the angular tilt of the output beam when averaged at 10 Hz for 1 second every 30 min under laboratory operating conditions
22. Maximum rms variation in the angular tilt of the output beam over a 1 second period.
23. Laser system output linearly polarized to > 95%.

### 3.1.2 Other Performance Requirements

#### 3.1.2.1 Laser Pulse Format

**REQ-LS-0165:** The GS laser system format shall be continuous wave mode-locked (CW ML).

**REQ-LS-0166:** The Keck I laser system format shall be CW ML.

#### 3.1.2.2 Output Beam Waist

**REQ-LS-0194:** Each output laser beam shall form a waist in the Laser System output plane defined in drawing number 89-GP-3110-0010. The exact beam waist location shall be within 10% of the Rayleigh range. For the GS laser system all five beams shall have the same waist position to within 1% of the Rayleigh range. Compliance is by design. The beam waist is defined as the point along the axis of the output beam where the radius of curvature for the laser wavefront is infinite.

#### 3.1.2.3 Output Beam Geometry

##### 3.1.2.3.1 GS Laser System

**REQ-LS-0230:** The laser output beam geometry at the output of the laser system shall be as shown in drawing numbers 89-GP-3110-0010 and 89-GP-3110-0011.

**REQ-LS-0235:** The output beam locations and directions of propagation with respect to the telescope shall be as shown in drawing numbers 89-GP-3110-0010 and 89-GP-3110-0011.

##### 3.1.2.3.2 Keck I Laser System

**REQ-LS-0236:** The output beam location and direction of propagation shall be as shown in drawing number 1750-C3002.

#### 3.1.2.4 Output Aperture

**REQ-LS-0237:** The Keck I laser system shall have a single output aperture.

### 3.1.3 Optical Performance Goals

#### 3.1.3.1 Adjustable total output power

It is a **goal** that the total laser output power be adjustable (laser technology permitting). At power levels other than the design full power, there is no guarantee regarding to compliance to any of the other optical specifications including but not limited to beam quality, central wavelength and stability, and power stability.

#### 3.1.3.2 Beam diameter

It is a **goal** that the GS laser output beams have a diameter that is 5.00 $^{+}$/- 0.25mm at the $1/e^2$ intensity points in the plane of the laser system output aperture

#### 3.1.3.3 This section deleted

#### 3.1.3.4 Tunability

As a **goal**, the central frequency of the output beams should be adjustable in steps of +/- 50MHz from the nominal central frequency.

#### 3.1.3.5 Out of Band Power

The **goal** for out of band power is 0.001 W. This goal is particularly important with regard to leakage light at IR wavelengths as IR light backscattered by the atmosphere can increase the effective background for IR wavelength observations. Note that this goal does not apply when the laser system is tuned off the exact sodium wavelength by means of the tuning facility required by §3.1.1.

#### 3.1.3.6 This section deleted

#### 3.1.3.7 This section deleted

#### 3.1.3.8 Polarization

As a **goal** the polarization of each and every output beam should be linear with a polarization ratio > 100:1.

## 3.2 Mechanical

### 3.2.1 Parametric Performance Requirements

#### 3.2.1.1 Transportation and Shipping Environment

**REQ-LS-0600:** When packaged as required in §3.2.2.2 all components of the laser system shall continue to meet all of the performance requirements defined in §3 without repair after a single shipment to the delivery location by any combination of air or surface transportation. For information, the expected conditions to be encountered during shipping are given in Table 7.

| *Parameter* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|
| Altitude | 0 | - | 4,572 | m | 1 |
| Temperature | -33 | - | 71 | ºC | 2, 3 |
| Temperature shock | -54 | - | 70 | ºC | 4 |
| Humidity | 0 | - | 100 | % | 5 |
| Gravity orientation | - | - | - | NA | 6 |
| Wind | - | - | 67 | m/s | 7 |
| Vibration | - | - | 0.015 | $g^2$/Hz | 8, 9 |
| Shock | - | - | 15 | g | 10 |
| Acceleration | | | | | |
| Due to transport | - | - | 4 | g | 11 |
| Due to seismic activity | - | - | 2 | g | 12 |

**Table 7: Transportation and Shipping Environment**

Notes:

1. See MIL-STD-810F Method 500 §2.3.1.
2. Maximum is for induced conditions, see MIL-STD-810F Method 501 Table 501.4-I.
3. Minimum is for induced conditions, see MIL-STD-810F Method 502 Table 502.4-II.
4. See MIL-STD-810F Method 503.
5. Relative, condensing.
6. Packaged equipment may be subjected to all possible gravity orientations during transportation and shipping.
7. Based on possible cargo helicopter air lift of a transport container.
8. 10-40 Hz, -6dB/oct. drop-off to 500 Hz, all axes.
9. See MIL-STD-810F Method 514.
10. 0.015 second half-sine, all axes.
11. All axes.
12. 0.5 Hz to 100Hz, all axes.

#### 3.2.1.2 Non-Operating Environment

**REQ-LS-0601:** All components of the laser systems shall meet all of the performance specifications defined in §3 with minor realignment after being subjected to any number of cycles of any of the non-operating environments defined in Table 8. These represent environments associated with normal non-operating telescope activities including but not limited to storage and handling within the facility and installation and removal from the telescope.

| *Parameter* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|
| Altitude | | | | | |
| GS | 0 | - | 2700 | m | |
| Keck I | 0 | - | 4300 | m | |
| Temperature | | | | | |
| GS | -10 | 9 | 20 | ºC | 1 |
| Keck | -10 | 0 | 20 | ºC | 1 |
| Rate of change | -0.8 | - | 0.8 | ºC/h | |
| Humidity | 0 | - | 90 | % | 2 |
| Gravity orientation | - | -1 | - | g | 3 |
| Vibration | - | - | $8.0x10^{-4}$ | $g^2$/Hz | 4 |
| Shock | - | - | 15 | g | 5 |
| Acceleration | | | | | |
| Due to handling | - | - | - | g | 6 |
| Due to seismic activity | - | - | 2 | g | 7 |

**Table 8: Handling Environment**

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20-1000Hz, 6db/oct drop- off to 2000Hz.
5. 0.015 second half-sine, all axes.
6. 2 g vertical, 1 g fore/aft, 0.5 g lateral
7. 0.5 Hz to 100Hz, all axes.

### 3.2.1.3 Operating Environment

**REQ-LS-0605:** The laser system operating environment is the ensemble of all conditions experienced under normal telescope operation when the laser system is installed in the laser service enclosure described in §3.2.2.3. All laser system performance requirements shall be met while the laser system is subjected to the operating environment conditions given in Table 9.

| *Parameter* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|
| Altitude | | | | | |
| GS | 0 | - | 2700 | m | |
| Keck I | 0 | - | 4300 | m | |
| Temperature | | | | | |
| GS | -10 | 9 | 20 | ºC | 1,2 |
| Keck | -10 | 0 | 20 | ºC | 1,2 |
| Rate of change | -0.8 | - | 0.8 | ºC/h | |
| Humidity | 0 | - | 90 | % | 3 |
| Gravity orientation | - | -1 | - | g | 4 |
| Vibration | - | - | $1x10^{-5}$ | $g^2$/Hz | 5 |

**Table 9: Laser System Operating Environment**

Notes:

1. The temperature of the laser service enclosure interior shall change no more than ±2 $^{o}$C over a 12 hr operating period.
2. Typical value is the average annual temperature.
3. Relative, non-condensing.
4. Normal to the earth's surface.
5. 20-1000Hz, 6db/oct drop- off to 2000Hz.

### 3.2.1.4 Mass and Size Constraints

| *Parameter* | *Requirement Number* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|---|
| Mass | | | | | | |
| GS | REQ-LS-0675 | - | - | 2600 | kg | 1 |
| Keck I | REQ-LS-0676 | - | - | 2350 | kg | 1 |
| Laser bench enclosure dimensions | | | | | | |
| GS | REQ-LS-0680 | - | - | 2320 x 3660 x 1150 | mm | 2,3 |
| Keck I | REQ-LS-0681 | - | - | 2320 x 2750 x 1150 | mm | 2 |
| Laser electronics enclosure dimensions | | | | | | |
| GS | REQ-LS-0685 | - | - | 2320 x 1270 x 980 | mm | 2,3 |
| Keck I | REQ-LS-0686 | - | - | 2320 x 1270 x 980 | mm | 2 |

**Table 10: Laser System Mass and Size Constraints**

Notes:

1. Total mass for laser bench enclosure and laser electronics enclosure
2. Height, width and depth of the total enclosure envelope. The height value represents the total vertical distance including clear space above and below the laser system enclosures. The width dimension does not include connector and like protrusions or brackets required for seismic restraint.
3. Per drawing numbers 89-GP-3110-0010 and 89-GP-3110-0011.

#### 3.2.1.5 Power Dissipation Requirements

Power dissipation requirements for the laser system are given in Table 11. The laser system shall operate normally when provided with the coolant conditions specified in §5.3.13.

| *Parameter* | *Requirement Number* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|---|
| Power dissipation | | | | | | |
| GS | | | | | | |
| To ambient | REQ-LS-0690 | - | - | 500 | Watts | |
| To coolant supply | REQ-LS-0691 | - | - | 15,000 | Watts | 1 |
| Keck I | | | | | | |
| To ambient | REQ-LS-0692 | - | - | 500 | Watts | |
| To coolant supply | REQ-LS-0693 | - | - | 10,000 | Watts | 1 |

**Table 11: Laser System Power Dissipation and Cooling Requirements**

Notes:

1. Coolant type, temperature, flow rates and pressure are specified in §5.3.13.

### 3.2.2 Other Performance Requirements

#### 3.2.2.1 Air Borne Contaminants

**REQ-LS-0606:** The weather conditions at the summit of sites of the observatories include frequent high winds resulting in some air borne contaminants, particularly dust and insects. Equipment must be protected during installation and handling against the entry of these contaminants, particularly optical surfaces, precision mechanisms and fine pitch or fiber optic connectors.

#### 3.2.2.2 Shipping Containers

**REQ-LS-0610:** All shipping containers must be designed to provide adequate protection for the equipment during transport. Unless otherwise specified single use containers suitable for the size, weight and shipment method to be employed are acceptable. For guidance in the design of suitable containers consult Air Transport Association (ATA) Spec 300, 2001.1 edition, "Specification for Packaging of Airline Supplies".

#### 3.2.2.3 Laser Service Enclosure

**REQ-LS-0611:** The laser system will be mounted inside a laser service enclosure (which is not part of the vendor's scope of work) in a gravity stable environment on the telescope Nasmyth platform. The laser service enclosure will provide a class 10,000 clean room environment.

#### 3.2.2.4 Component Ratings

##### 3.2.2.4.1 Safety Factors

**REQ-LS-0725:** Safety factors for structural elements and fasteners of lifting and handling features shall meet the requirements specified in Reference Document #12 where applicable.

**REQ-LS-0726:** Safety factors for general structural elements shall meet the requirements specified in Reference Document #12 where applicable.

##### 3.2.2.4.2 Design Lifetime

**REQ-LS-0727:** All mechanical moving parts shall be selected for a 10 year operating lifetime in the operating environments specified in §3.2.1.3.

### 3.2.3 This section deleted

### 3.3 Electrical/Electronic

#### 3.3.1 Parametric Performance Requirements

Power supply requirements for the laser system are given in Table 12.

##### 3.3.1.1 Power Supply

| *Parameter* | *Requirement Number* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|---|
| Power input | | | | | | |
| GS | | | | | | |
| Voltage | REQ-LS-0785 | 187 | 208 | 229 | Vac | 1 |
| Current | REQ-LS-0786 | - | - | 60 | Amperes | 2 |
| Frequency | REQ-LS-0787 | 47 | 50 | 53 | Hz | |
| Power factor | REQ-LS-0784 | 0.6 | - | - | - | |
| Keck I | | | | | | |
| Voltage | REQ-LS-0796 | 187 | 208 | 229 | Vac | 1 |
| Current | REQ-LS-0797 | - | - | 40 | Amperes | |
| Frequency | REQ-LS-0798 | 57 | 60 | 63 | Hz | |
| Power factor | REQ-LS-0799 | 0.6 | - | - | - | |

**Table 12: Laser System Power Supply Requirements**

Notes:

1. Voltage given is phase to phase for a three phase, 4 wire and ground service.
2. Two 30A circuits.

#### 3.3.2 Other Performance Requirements

##### 3.3.2.1 Power Failure

**REQ-LS-0788:** The laser system will not be provided with an uninterruptible power supply (UPS) or other back-up power source. The laser system must be able to tolerate a total power failure, including loss of glycol cooling, without permanent damage to any component.

##### 3.3.2.2 Wire and Cable Ratings

**REQ-LS-0789:** All wire and cable should be rated for an ambient temperature range of -30 °C to 100 °C.

### 3.4 Safety

Safety requirements for the laser system are covered in §5, Functional Requirements.

## 3.5 Software

### 3.5.1 Parametric Performance Requirements

#### 3.5.1.1 Reliability

**REQ-LS-1340:** All vendor supplied laser control system software components shall be tested with the fully integrated laser system under simulated operating conditions and shall achieve at least 150 hours of continuous operation without a fault. Prior to conducting the tests the vendor shall submit to AURA for approval a software verification and validation plan consistent with IEEE standard 1012-2004 "Standard for Software Verification and Validation".

#### 3.5.1.2 Fiber Optic Data Links

**REQ-LS-1341:** Where fiber optic data links are used such links must tolerate up to 10 dB of attenuation due to interconnection losses without impairment of performance or reliability.

#### 3.5.1.3 Display Updates

**REQ-LS-1342:** Graphical user interface software shall update all displayed laser system parameters at the update rates defined in §4.1.2

### 3.5.2 Operational Performance Requirements

#### 3.5.2.1 Error Recovery

##### 3.5.2.1.1 Loss of Network Connections

**REQ-LS-1343:** All laser control system software should gracefully recover from the interruption of TCP/IP network connections or fiber optic connections at any time. This disconnection may occur due to physical interruption of the network connection, or the power cycling or hardware reset/reboot of the device at the other end of the network connection. Software should implement reasonable timeouts and handle all TCP/IP network errors so that recovery from a network fault is as automatic as possible. Specifically, the components that have not experienced power cycling or a hardware reset/reboot must recover from the loss of the network connection without requiring that they be reset or rebooted.

Whenever possible it is expected that the system will perform in a manner that permits recovery from any of the following conditions without requiring manual resetting of any hardware component and where practical without loss of data:

1. Loss of network or data connections:
    a. Laser control system internal network (if any)
    b. Laser control system server to observatory network
2. Power cycling:
    a. Laser control system
    b. Laser control system server
    c. Observatory network switches
    d. Laser system EPICS client
3. Hardware resets:
    a. Laser control system server
    b. Laser system EPICS client

When recovery is not possible, and for the cases where the host computer is not the system being reset or power cycled, the user interface software in the system shall provide a useful diagnostic message or warning to the operator without crashing or locking up.

#### 3.5.2.1.2 This section deleted

### 3.5.2.2 Execution Speed and Command Latency

**REQ-LS-1345:** The response time requirements for the laser control system software shall conform to the requirements given in Table 13.

| *Software Function* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|
| Status requests | - | 0.1 | 0.2 | s | |
| Configuration commands | - | 0.1 | 0.2 | s | |
| Emergency shutdown (§4.5.5.2) | - | 0.01 | 0.05 | s | |
| Application software startup and initialization | - | <10 | 30 | s | 1 |

**Table 13: Software Latencies**

Notes:

1. Not including the actual time required to perform the operating system re-boot and associated initializations.

## 3.6 Interfaces

Interface requirements for the laser system are covered in §5, Functional Requirements.

# 4 OPERATIONAL REQUIREMENTS

## 4.1 Optical

### 4.1.1 Laser Shutters

**REQ-LS-0340:** A single laser shutter shall be provided for all output beams from the laser system. This shutter shall be 100% opaque at all wavelengths present in the output beam and shall be able to remain closed for an indefinite amount of time. When the shutter is closed there shall not be any additional heat load presented to the ambient environment.

**REQ-LS-0345:** The laser shutter shall close in one second or less. Shutter opening will take 5 seconds as required for compliance with CDRH laser safety requirements.

**REQ-LS-0350:** The laser shutter shall be controlled both manually via hardware and remotely via software. It shall be possible to open and close the laser shutter at all times via hardware and software control except in the condition set forth in REQ-LS-0843 in §5.6.2.

### 4.1.2 Measurement Facilities

The laser system shall be provided with the output beam measurement facilities described in REQ-LS-0351 through REQ-LS-0396.

**REQ-LS-0351:** Unless noted otherwise all of the measurement facilities described in this section shall be interfaced to a data acquisition system controlled by, and preferably incorporated in, the laser control system computer. This data acquisition system shall permit the laser control system software described in §5.7 to input, process, monitor and report the data acquired from each of the measurement facilities described in this section.

**REQ-LS-0353:** Where more than one output beam is provided by the laser system all measurement facilities shall be provided for each of the output beams simultaneously unless noted otherwise. All measurements shall be made over a wavelength range consistent with the laser light wavelengths present in the system at the point where the measurement is made. Unless otherwise specified the full scale range of each measurement shall be adequate for the parameter being measured.

**REQ-LS-0355:** An output power measurement facility shall be provided for each laser system output beam at all times. This measurement shall be made in the plane of the laser system output aperture. For a laser system with multiple output beams derived from a single source and a single power measurement is made, the measurement shall be made prior to splitting the beam. Power of the individual beams shall be in accordance with REQ-LS-0110. The laser system vendor shall provide full-scale calibration data for each power measurement channel provided in the laser system. The total power measurement facility shall provide the measurements listed in Table 14.

| ***Measurement*** | ***Measurement Units*** | ***Measurement Accuracy*** | ***Update rate*** | ***Notes*** |
|---|---|---|---|---|
| Output power | | | | |
| Per beam | W | ± 5% | > 0.2 Hz | 1 |
| Total output power | W | ± 5% | > 0.2 Hz | 1 |

**Table 14: Output Power Measurement Requirements**

Notes:
1. Each value time stamped.

**REQ-LS-0360:** The laser system shall include at least one sodium vapor cell fluorescence detection system in order to derive the absolute laser wavelength for each output laser beam in accordance with REQ-LS-0140. This system shall be available at all times for fluorescence detection. Where more than one output beam is provided by the laser system and the laser system configuration makes it possible that all beams may not have exactly the same nominal central wavelength, a user controlled remotely operated facility shall be provided for selection of the desired beam.

**REQ-LS-0361:** This requirement deleted.

**REQ-LS-0365:** A central frequency deviation measurement facility shall be provided for each laser system output beam at all times. Where more than one output beam is provided by the laser system and the laser system configuration is such that it is not possible for the nominal central wavelength of each of the beams to differ, then the central frequency deviation measurement facility shall be provided for one output beam only. The measurement shall be presented in terms of deviation from the frequency of the highest peak of the sodium D2 line. The laser system vendor shall provide full scale calibration data for each wavelength measurement channel provided in the laser system. The central wavelength measurement facility shall provide the measurements listed in Table 15.

| ***Measurement*** | ***Measurement Units*** | ***Measurement Accuracy*** | ***Update rate*** | ***Notes*** |
|---|---|---|---|---|
| Central frequency | | | | |
| Per beam | MHz | ± 50 MHz | > 0.2 Hz | 1,2,3 |

**Table 15: Central Wavelength Deviation Measurement Requirements**

Notes:
1. Each value time stamped.
2. Measured relative to the highest peak of the sodium D2 line.
3. Full scale range at least 6 GHz.

**REQ-LS-0370:** A spectral bandwidth measurement facility shall be provided that allows monitoring of the spectral bandwidth for each laser system output beam via connectors provided on the laser system. Where more than one output beam is provided by the laser system and the laser system configuration is such that it is not possible for the spectral bandwidth of each of the beams to differ, then the spectral bandwidth measurement facility shall be provided for one output beam only. The communications standard and output data format for these connections is to be specified by the vendor. The laser system vendor shall provide full scale calibration data for the spectral bandwidth measurement facility. The spectral bandwidth measurement facility shall provide the measurements listed in Table 16.

| ***Measurement*** | ***Measurement Units*** | ***Measurement Accuracy*** | ***Update rate*** | ***Notes*** |
|---|---|---|---|---|
| Spectral Bandwidth | | | | |
| FWHM | MHz | ± 50 MHz | > 0.2 Hz | 1,2 |

**Table 16: Spectral Bandwidth Measurement Requirements**

Notes:
1. CW ML output beams are assumed.
2. Full scale range at least 6 GHz.

**REQ-LS-0375:** A temporal profile measurement facility consisting of a fast photodiode and BNC cable interface shall be provided to allow monitoring of the temporal profile for each laser system output beam. Where more than one output beam is provided by the laser system and the laser system configuration is such that it is not possible for the temporal characteristics bandwidth of each of the beams to differ, then the temporal profile measurement facility shall be provided for one output beam only. The laser system vendor shall provide full scale calibration data for the temporal profile measurement facility. The temporal profile measurement facility shall provide the measurements listed in Table 17.

| *Measurement* | *Measurement Parameters* | *Measurement Units* | *Measurement Accuracy* | *Update rate* | *Notes* |
|---|---|---|---|---|---|
| Temporal profile | | | | | |
| | Time | N/A | ± 50 ps | ≥ 1 per min | 1 |
| | Intensity | N/A | ± 5 % | ≥ 1 per min | 1 |
| Pulse length FWHM | | | | | |
| | Time | N/A | ± 50 ps | > 0.2 Hz | 1 |
| Pulse Repetition Frequency (PRF) | | | | | |
| | PRF | N/A | ± 5 % | > 0.2 Hz | 1 |

**Table 17: Temporal Profile Measurement Requirements**

Notes:

1. CW ML output beams are assumed.

**REQ-LS-0385:** The laser system vendor shall integrate into the laser system a Coherent Inc. "ModeMaster PC" (MM) $M^2$ beam propagation analyzer. The MM configuration shall be selected by the vendor to accommodate the wavelength range and divergence appropriate for the laser system output beam or beams. Where more than one output beam is provided by the laser system, facilities shall be provided to permit selection of each beam for analysis by the MM unless the laser system configuration is such that it is not possible for the beams to differ in spatial characteristics. The ModeMaster PC measurement plane shall be located as close as possible to the laser system output aperture so as to represent the spatial characteristics of the actual output beam or beams and minimize non-common path measurement errors.

**REQ-LS-0390:** The MM shall be controlled by the laser system software. The laser system software shall support the measurement features of the MM listed in Table 18. The laser system software shall time stamp each measurement. Units for each measurement shall be consistent with the units used in the standard MM control software supplied by Coherent Inc. for use with MM.

| **MM Measurement Type** |
|---|
| Beam Quality - $M^2$ |

**Table 18: Laser System Software Supported MM Measurements**

**REQ-LS-0395:** The laser system software shall provide a software switch to allow enabling or disabling control of the MM by the laser system software. When the switch is in the disable position it shall be possible to launch and run the standard MM control software supplied by Coherent Inc. for use with MM on the laser system control computer without having to shut down the laser system software. When the standard MM control software supplied by Coherent Inc. for use with MM is terminated it shall be possible to enable control of the MM by the laser system software without having to shut down or restart the laser system software.

**REQ-LS-0396:** A beam profile measurement facility shall be provided for each laser system output beam at all times. Where more than one output beam is provided by the laser system and the laser system configuration is such that it is not possible for the spatial characteristics of each of the beams to differ, then the beam profile measurement shall be provided for one output beam only. One beam profile measurement shall be made in a plane equivalent to the plane of the laser system output aperture. This measurement shall be provided at a location as close as possible to the laser system output aperture so as to represent the spatial characteristics of the actual output beam and minimize non-common path measurement errors.

| *Measurement* | *Measurement Axis/Parameters* | *Measurement Units* | *Measurement Accuracy* | *Update rate* | *Notes* |
|---|---|---|---|---|---|
| Beam profile | | | | | |
| | X, Y | μm | ± 50 μm | ≥ 2 per min | 1 |
| | Intensity | counts | N./A | ≥ 2 per min | 1 |
| Transverse diameter at $1/e^2$ intensity points | | | | | |
| | $w_{0,X}$ | μm | ± 50 μm | > 2 per min. | 1 |
| | $w_{0,Y}$ | μm | ± 50 μm | > 2 per min. | 1 |

**Table 19: Beam Profile Measurement Requirements**

Notes:

1. Each value time stamped.

**REQ-LS-0397:** This requirement deleted.

### 4.1.3 Optical Operational Goals

#### 4.1.3.1 Measurement Facilities

All measurements provided in support of optical performance measurement goals should be made over a wavelength range consistent with the laser light wavelengths present in the system at the point where the measurement is made. For all measurements made in units of µrad a user selectable conversion to arc seconds should be provided.

As a **goal**, the output power measurement facility should provide time history data logging.

As a **goal** vendor shall provide splitters to enable external monitoring of the 1319 and 1064 oscillator pulses using AURA supplied equipment.

As a **goal**, the central frequency deviation measurement facility should provide time history data logging.

As a **goal**, the beam quality measurement facility should provide time history data logging.

## 4.2 Mechanical

### 4.2.1 Cooling System Monitoring

**REQ-LS-0425:** All cooling systems shall be provided with temperature monitoring. Measurement accuracy and data update rate are as specified in REQ-LS-0430

A flow switch shall be provided to generate a loss of coolant alarm. This flow switch should interrupt power to the affected system unless a separate over-temperature detection system is provided to remove power from the affected system.

## 4.3 Electrical/Electronic

The laser system shall be provided with the monitoring and measurement facilities described in REQ-LS-0430 through REQ-LS-0442. The full scale range of each measurement shall be adequate for the expected maximum range of the parameter being measured.

**REQ-LS-0427:** Unless noted otherwise all of the measurement facilities described in this section shall be interfaced to a data acquisition system controlled by, and preferably incorporated in, the laser control system computer. This data acquisition system shall permit the laser control system software described in §5.7 to input, process, monitor and report the data acquired from each of the measurement facilities described in this section.

### 4.3.1 Cooling System Monitoring

**REQ-LS-0430:** Coolant temperature shall be monitored at all times for all cooling systems of the laser system. The coolant temperature measurements shall be as specified in Table 20.

| *Measurement* | *Measurement Units* | *Measurement Accuracy* | *Update rate* | *Notes* |
|---|---|---|---|---|
| Coolant temperature | ºC | ± 0.5 ºC | > 0.2 Hz | 1 |

**Table 20: Coolant Temperature Measurement Requirements**

Notes:
1. Each value time stamped.

**REQ-LS-0435:** This requirement deleted.

### 4.3.2 Operating Hours Monitoring

**REQ-LS-0440:** The accumulated hours of laser system operation shall be monitored at all times. An input power operated electromechanical non-resettable operating hours meter with a minimum resolution of 0.1 hours shall be provided. The meter shall register power on durations of 0.1 hours or more. An additional electromechanical non-resettable operating hours meter shall be provided to measure accumulated hours of operation for one of the laser system master oscillators. The operating hours meters shall be located in the laser electronics enclosure. Access to the operating hours meters may require powering off the laser system.

Additional facilities shall be provided to monitor operating hours in software as described in §5.7.6.3.

#### 4.3.2.1 Enclosure Temperature

**REQ-LS-0442:** The internal temperature of all laser system enclosures shall be monitored at all times. The temperature measurements shall be as specified in Table 21.

| *Measurement* | *Measurement Units* | *Measurement Accuracy* | *Update rate* | *Notes* |
|---|---|---|---|---|
| Enclosure temperature | | | | |
| Temperature | ºC | ± 0.5 ºC | > 0.2 Hz | 1 |
| Dew Point | ºC | ± 1 ºC | > 0.2 Hz | 1 |

**Table 21: Enclosure Temperature Measurement Requirements**

Notes:
1. Each value time stamped.

#### 4.3.2.2 Overcurrent Protection

**REQ-LS-0417:** A fuse or circuit breaker shall internally protect all AC line connected equipment. When a time delay fuse or time delay breaker is used the rating of the breaker shall not exceed 150% of the continuous full load current of the connected load. Where a non-time delay fuse is used the rating of the fuse shall not exceed 150% of the continuous full load current of the connected load. Where an instantaneous trip breaker is used the rating of the breaker shall not exceed 250% of the continuous full load current of the connected load.

The panel where the fuse or circuit breaker is located shall be clearly marked with the type and rating of the protective device.

#### 4.3.2.3 Altitude Derating

**REQ-LS-0419:** For the Keck I laser system the voltage ratings of relays, switches and insulated cables shall be reduced to 80% of their rated value due to the altitude at the summit of Mauna Kea. Electrical spacings (air gaps and creep distances) shall also be increased by a factor of 1.25 to compensate for the increased altitude.

The normal dielectric withstand test specification for UL approved or listed components for use in AC line connected equipment operating from 120/240 Vac is 2500 Vac, 60 Hz for one minute. Voltage ratings for all components shall be checked for safety margin with respect to this rating using the following equation:

$$VI = \frac{2 * V + 1000}{AF}$$

where:

VI is the voltage isolation required for the altitude

AF is the altitude factor of 0.8 for 15,000 feet

V is the sea level rated working voltage

For the Keck I laser system the resulting value for VI shall be less than the dielectric withstand test specification voltage (2500 Vac) or a dielectric withstand test at altitude shall be performed to ensure that the system is safe for the intended application. Compliance to this requirement for COTS items and existing CTI designs shall be subject to manufacturers specification and availability.

#### 4.3.2.4 Power Ratings

**REQ-LS-0420:** For the Keck I laser system all power dissipating components to be cooled by free air convection must be derated to 80% of their sea level absolute maximum average power dissipation ratings.

### 4.3.3 Electrical/Electronic Operational Goals

#### 4.3.3.1 This section deleted.

## 4.4 Safety

#### 4.4.1.1 Emergency Shutdown

**REQ-LS-0328:** The laser system shall provide a fully hardware based total power down facility that powers down all subsystems of the laser system (including the laser control system computer) in response to activation of either the laser system emergency stop pushbutton (see §5.6.5.1) or the observatory/telescope emergency stop signaling system (see §5.6.5.2).

**REQ-LS-0329:** The total power down shall occur immediately when the emergency stop pushbutton is activated or when the observatory/telescope emergency stop signaling system is activated, regardless of the possibility of damage to any components due to the immediate total power down. Vendor shall minimize by design and test the possibility that such damage will occur and vendor shall provide to AURA a list of components that may be damaged by an immediate total power down. The total power down shall cause the laser shutter to fully close.

## 4.5 Software

### 4.5.1 Configuration Files

**REQ-LS-0300:** Unless otherwise noted all user configurable parameters provided by the laser control system software shall be controlled by configuration files. A means shall be provided in the laser control system software to determine the settings of all user configurable parameters and store their values in a configuration file. A default configuration file shall also be provided and shall be separate from the user configuration files. The default configuration file shall also be an editable file and the laser control system software shall be delivered with a reasonable set of default values for every user configurable parameter.

#### 4.5.1.1 This section deleted.

### 4.5.2 Normal Operation

**REQ-LS-0302:** The laser control system software shall automate all laser functions during normal operation and shall provide remote control facilities for all normal laser functions. During normal operation the laser control system software shall require a minimum of user interaction to change laser operating modes, including start-up and shutdown.

### 4.5.3 Start-up

**REQ-LS-0305:** A software controlled start-up procedure shall be provided for the laser system that allows a remote control facility, such as that provided by the Gemini or WMKO control system software to initiate an automated sequence to start-up the laser system and configure the laser system to full power according to a pre-determined operating configuration including automatic setting of all user configurable parameters. The start-up procedure will automatically run the internal test sequence required in REQ-LS-0310.

**REQ-LS-0315:** The laser system start-up procedure shall take no longer than 30 minutes, including all possible internal tests performed one time each. The start-up procedure shall stop if any of the internal tests in the internal test sequence fail. Once the fault is cleared it shall be possible to restart the start-up procedure from the beginning.

### 4.5.4 Internal Test Sequence

**REQ-LS-0310:** The laser control system software shall provide for a pre-determined sequence of internal tests. The laser control system software shall generate an error message and abort the start-up procedure if the results of any of the internal tests produce values out of the range specified for the test.

### 4.5.5 Shutdown

#### 4.5.5.1 Normal Shutdown

**REQ-LS-0320:** A software controlled normal shutdown procedure shall be provided for the laser system that allows a remote control facility, such as that provided by the Gemini or WMKO control system software to initiate an automated sequence to shutdown the laser system. At the start of the normal shutdown procedure the laser shutter shall close.

**REQ-LS-0325:** The laser system normal shutdown procedure shall take no longer than is required to establish safe shutdown conditions, including a safe temperature for the cessation of coolant flow. Unless safe shutdown conditions require it, the total time required for a normal shutdown shall not exceed 30 minutes.

#### 4.5.5.2 Software Controlled Emergency Shutdown

**REQ-LS-0330:** A software controlled emergency shutdown procedure shall be provided for the laser system that allows a remote control facility, such as that provided by the Gemini or WMKO control system software to initiate an emergency shutdown.

**REQ-LS-0331:** The software controlled emergency shutdown shall immediately close the laser shutter. The power down of all laser system components shall take place as rapidly as possible when the emergency shutdown is initiated by software command, consistent with the avoidance of damage to any laser system components due to the power down of the laser system.

### 4.5.6 Measurement and Monitoring Facilities

**REQ-LS-0410:** The laser control system software shall provide logging and real time display facilities for all of the data acquired by the data acquisition system controlled by, and preferably incorporated in, the laser control system computer from the measurement and monitoring capabilities required in §4.1.2 and §4.3.

**REQ-LS-0412:** The laser system vendor shall provide additional monitoring and display facilities as required to verify the state of all critical internal sensors, interlocks and fault sensors provided as part of the laser system. These additional monitoring facilities shall be interfaced to the data acquisition system controlled by, and preferably incorporated in, the laser control system computer, permitting the laser control system software described in §5.7 to input, process, monitor and report the data acquired from each of the additional vendor provided monitoring facilities.

**REQ-LS-0414:** Any additional monitoring and display facilities provided by the vendor shall provide an update rate of at least 0.2 Hz. The full scale range of each measurement shall be adequate for the expected maximum range of the parameter being measured.

**REQ-LS-0416:** This requirement deleted.

## 4.6 Interfaces

Interface requirements for the laser system are covered in §5, Functional Requirements.

# 5 FUNCTIONAL REQUIREMENTS

## 5.1 COTS and Third Party Components

**REQ-LS-0156:** Vendor shall be responsible for ensuring that all COTS and third party components and subassemblies supplied as part of the laser system not bearing a UL or CE mark conform to the requirements of §3.2.1, §5.3 and §5.4. Where this is not possible vendor will provide documentation on the COTS or third party components and subassemblies for examination by AURA.

## 5.2 Optical Requirements

Optical requirements for the laser system are given in §3, Performance Requirements, and §4, Operational Requirements.

## 5.3 Mechanical

### 5.3.1 Laser System Enclosures

**REQ-LS-0670:** All enclosures for electrical and electronic components must perform in a manner that complies with the conducted and radiated emissions and susceptibility requirements of REQ-LS-0860.

**REQ-LS-0671:** Enclosures for electrical/electronic components and wiring shall conform to the applicable requirements of REQ-LS-0860. Vendor will also follow guideline 1 "SAFETY DESIGN CRITERIA - PERSONNEL HAZARDS" of MIL-HDBK-454A "General Guidelines for Electronic Equipment".

**REQ-LS-0672:** This requirement deleted.

#### 5.3.1.1 Access and Covers

**REQ-LS-0635:** Components requiring routine service or maintenance should be accessible by removing a single cover secured by no more than 8 fasteners.

**REQ-LS-0715:** Covers that may be removed in a location where fasteners could fall into the interior of the enclosure shall be equipped with captive fasteners. Captive fasteners shall be of the threaded type and not captivated by swaged sleeve fittings. Quarter turn fasteners engaging spring hooks are specifically discouraged for reasons of fit and reliability.

Whenever possible service access provisions should be provided that do not require disassembly of the entire system or subsystem to access motors or switches for replacement.

#### 5.3.1.2 Enclosure Configuration

**REQ-LS-0637:** The laser system shall utilize one or more enclosures as required. The number of enclosures shall be minimized and it is preferred that all laser system electronics be contained in a single enclosure.

**REQ-LS-0636:** Thermal analysis shall be performed to ensure that all subsystems within each enclosure will operate within their temperature limits and to ensure that excess heat is not transmitted to other subsystems within the enclosure.

#### 5.3.1.3 Laser Bench Enclosures

All laser system enclosures housing optical components shall meet requirements REQ-LS-0650 through REQ-LS-0660.

**REQ-LS-0640:** This requirement deleted.

**REQ-LS-0650:** The enclosure shall be designed so as to prevent dust from entering the enclosure.

**REQ-LS-0655:** The enclosure shall be designed so as to prevent condensation inside the enclosure.

**REQ-LS-0656**This requirement deleted.

**REQ-LS-0660:** For every laser system output aperture the enclosure shall include an optical quality (flatness to 1/10 λ or better at 589.0 nm) anti-reflection coated (at 589.0 nm) window to seal the enclosure from the outside environment and prevent air turbulence created by air exchange between the enclosure and the ambient. The optical properties of the window shall be such that the laser system optical performance requirements given in §3.1.1 are met after the output beam passes through the window. In addition, the optical window shall have a wedge shaped cross section in order to prevent formation of interference fringes in any output laser beam.

### 5.3.2 Fit and Finish

**REQ-LS-0770:** All steel or iron components shall be plated or painted to prevent rust. This includes fasteners and rivets. Welds not ground to the surface or joint profile should be of dress quality. All welds and castings shall be stress relieved prior to painting and assembly.

**REQ-LS-0771:** Aluminum components shall be anodized unless function dictates otherwise (for example for special surface treatments or painting for anti-reflection purposes or to lower emissivity).

**REQ-LS-0772:** Machined components should be free of tool marks, scratches and material flaws such as inclusions or voids.

**REQ-LS-0773:** All burrs and sharp edges shall be removed from all fabricated components unless the function of the component requires a sharp edge.

**REQ-LS-0774:** Unless otherwise specified all external enclosure and exposed structural elements should be finished in epoxy paint applied in accord with the manufacturer's instructions.

**REQ-LS-0775:** Mild steel surfaces that cannot be painted for functional reasons (such as accurate interface surfaces) shall be protected by a non-tracking anti-corrosion dry film lubricant.

### 5.3.3 Continuity of Shielding and Grounding

**REQ-LS-0776:** Grounding and shielding shall conform to the applicable requirements (fixed ground equipment) sections of MIL-STD-464 "Electromagnetic Environmental Effects, Requirements for Systems". The laser system vendor shall in particular take care to meet the requirements of 5.10 and 5.11. Vendor shall test the system ground integrity and ensure that the bonding resistance limit for Class H for shock hazard (0.1 ohm) as described in Appendix section A5.10 is met by all laser system grounds and enclosures including doors and covers. Vendor will also follow guideline 1 "SAFETY DESIGN CRITERIA - PERSONNEL HAZARDS" of MIL-HDBK-454A "General Guidelines for Electronic Equipment".

### 5.3.4 Corrosion resistance

**REQ-LS-0777:** All metal components should be finished to prevent corrosion in the operating environment (see Table 9) over a normal 10 year lifetime of operation including handling, maintenance and repair. All removable fasteners must be plated or treated to prevent corrosion.

**REQ-LS-0778:** Internal components may be plated or paint finished. A contractor who can show conformance to the requirements of MIL-STD-171E "Finishing of Metal and Wood Surfaces" or equivalent shall perform any required painting, plating or anodizing.

### 5.3.5 Fasteners

**REQ-LS-0699:** This requirement deleted.

**REQ-LS-0696:** Press fit studs or threaded inserts must be installed in the correct material according to the manufacturer's instructions. Self tapping screws shall not be used for removable covers or to secure components that will have to be removed for repair or replacement.

**REQ-LS-0697:** With the exception of COTS components and subsystems, fasteners shall have either Phillips or hex socket heads. Hex socket button head fasteners should not be used except where space or specific function requires them. Undercut flathead machine screws should not be used except in special cases where there is no other appropriate design alternative.

**REQ-LS-0698:** With the exception of COTS components or subsystems, fasteners shall be locked when necessary or appropriate. Prevailing torque locknuts or lock washers are preferred over thread locking compounds. Soft insert locknuts should have Kel-F or Vespel inserts, and should only be used where subsequent removal is not anticipated.

### 5.3.6 Lubricants

**REQ-LS-0673:** Lubricants shall be selected for suitability to low temperature environments with an average operating temperature of 0 ºC. Greases using synthetic base oils such as Fluoroether or Silicone are preferred.

### 5.3.7 Lubricated Components

**REQ-LS-0674:** Externally mounted components with exposed lubricated parts such as gear trains or lead screws shall be enclosed in a shroud or boot to prevent the collection of dust and dirt and also to prevent accidental contact that may result in the transfer of the lubricant to other surfaces.

### 5.3.8 Structural

**REQ-LS-0678:** The structure of all enclosures supplied with the Keck I laser system shall be designed to meet the zone 4[1] earthquake survival requirements of Telcordia Standard GR-63-CORE, "NEBS™ Requirements".

[1] The United States Geological Survey (USGS) has assigned the big island of Hawaii to seismic zone 4. The seismic zone system is defined in the "International Building Code" (IBC) published by the International Code Council (ICC) in 2003.

### 5.3.9 Design Approach

#### 5.3.9.1 Opto-mechanical and Electro-optical Systems

**REQ-LS-0700:** Modules or components that must be removed for service shall be provided with locating pins or other features as required to permit repeatable removal and replacement.

**REQ-LS-0701:** This requirement deleted.

**REQ-LS-0702:** This requirement deleted.

**REQ-LS-0703:** This requirement deleted.

**REQ-LS-0705:** Handling features shall be provided on all components unless they are inherently easy to handle without risk of damage. Handles shall be provided (preferably fixed) for components up to 25 kg. Heavier components and subassemblies shall be provided with lifting eyes or 'A' brackets.

**REQ-LS-0706:** Wherever possible, handling provisions, fixtures and stands should be designed for safe operation and with consideration for ergonomic factors such as range of motion and working posture.

**REQ-LS-0707:** Mechanical and optical systems shall be capable of being repaired or, alternatively, replaced, without removing the laser system from its installed location.

#### 5.3.9.2 Electronic Systems

**REQ-LS-0708:** The mechanical arrangement of new electronic assemblies within enclosures shall consider and implement, where applicable, the guidelines and principals contained within MIL-HDBK-454A "General Guidelines for Electronic Equipment"., guideline 9 "WORKMANSHIP" and guideline 69 "INTERNAL WIRING PRACTICES". Service access and regulatory compliance in electronic assemblies and enclosures requires attention to the dimensions of components and the space provided for terminal access, wire bending and component mounting.

**REQ-LS-0709:** All removable modules shall be equipped with positive retention features. Extraction handles shall be provided for all connectorized plug-in modules.

**REQ-LS-0845:** Access to electronic modules and cabling shall be designed to facilitate in situ monitoring of electronic performance, troubleshooting and module replacement. Clearly labeled test points shall be provided for signals and voltages useful for module testing and fault diagnosis. Some critical test points will be accessible without disassembly of the module or removal of the module from the system, as needed.

**REQ-LS-0846:** All electronic modules shall be capable of being repaired or, alternatively, replaced, without removing the laser system from its installed location.

#### 5.3.9.3 Materials Selection

**REQ-LS-0780:** Where elastomeric components and flexible tubing are required, such materials shall be selected from materials that are resistant to elevated ozone levels and prolonged low relative humidity.

**REQ-LS-0781:** Lubricants must be selected from materials that function, with minimum outgassing, at low temperatures appropriate for the environments listed in Table 7, Table 8 and Table 9.

**REQ-LS-0782:** The materials listed in Table 24 shall not be used in any system delivered to WMKO.

| Material Type | Common Name | Reason(s) for Unsuitability |
|---|---|---|
| Adhesive, insulator | RTV silicone rubber[1] | Outgases during curing |
| Adhesive | Cyanoacrylates | Outgases during curing, subject to hydrolytic degradation |
| Conductor | Mercury[2] | Reactive, salts formed are toxic |
| Insulator | Acrylic[4] | Outgases, hygroscopic, brittle at low temperatures |
| Plated finish | Cadmium[2] | Outgases, reactive, hazardous |
| Insulator | Cellulose Acetate Butyrate | Hygroscopic |
| Insulator | Glass-Reinforced Extruded Nylon | Outgases, hygroscopic |
| Insulator | Kapton | Subject to hydrolytic degradation |
| Insulator | Neoprene | Outgases, subject to degradation by ozone and UV exposure |
| Insulator | Nylon[5] | Outgases, subject to degradation by ozone and UV exposure |
| Insulator | Phenolic[3] | Hygroscopic |
| Insulator | Polychlorinated Biphenyls[2] | Combustion produces highly toxic gases |

**Table 22: Materials not Acceptable to WMKO**

Notes:

1. Neutral cure RTV silicones may be acceptable provided that the cured silicone and the surrounding area are cleaned after assembly.
2. Use is or soon will be highly regulated.
3. Electrical grade phenolic is not hygroscopic.
4. Cast acrylic resin
5. Cable ties of weather resistant Nylon 6/6 (carbon black additive) are acceptable.

### 5.3.10 Vibration Control

**REQ-LS-0730:** Vibration isolation shall be employed as required to isolate sources of vibration within the laser system due to moving components such as fans, pumps and motors.

The Keck I laser system shall meet all performance and operating requirements when installed in a vibration environment that conforms to the Generic Vibration Criteria[2] Curve "C" as shown in Figure 1. The Keck I laser system shall not produce vibrations that result in rms velocities in excess of those given in curve "C" of Figure 1.

[2] Gordon, Colin G. *Generic Criteria for Vibration-Sensitive Equipment*. Proceedings of the SPIE Vol. 1619, pp. 71-85, Vibration Control in Microelectronics, Optics, and Metrology. Gordon, Colin G. editor. SPIE 1992.

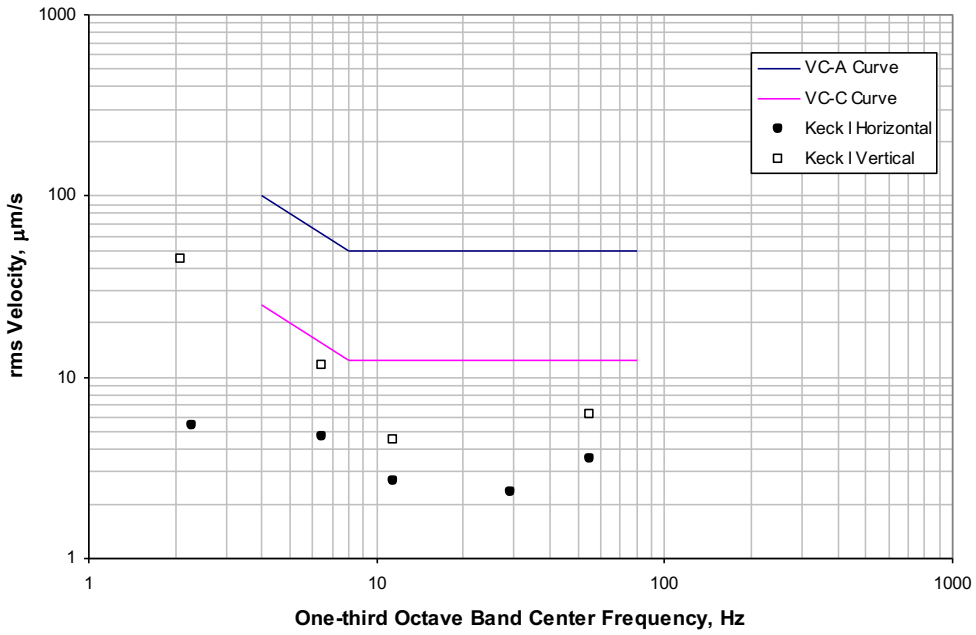


**Figure 1: Keck I Telescope Equipment Vibration Limits**

### 5.3.11 Audible Noise

**REQ-LS-0732:** Unless otherwise specified or accepted the laser system and any pumps, motors, outboard electronics or computers shall not at any time produce audible noise in excess of 85 dBA at a distance of 1 meter. This includes intermittent noises from pumps and variable speed cooling fans. Audible warning signals for emergency or fault conditions must be provided with a silence after delay feature or a manual silencing switch.

### 5.3.12 Cooling Systems

#### 5.3.12.1 Cooling System Components

**REQ-LS-0909:** All glycol cooling shall be plumbed to meet the requirements defined in REQ-LS-0913 using primarily stainless steel fittings. Custom manifolds should be used rather than arrangements of "T" fittings and hose. Where flexible hose is required, braided stainless steel hose is preferred. When other types of flexible hose are required the laser system vendor shall seek approval from AURA and WMKO for the type of hose to be used. Permanent connections should be made with JIC 37º flare compression fittings or SAE straight thread O-ring fittings. Teflon tape should not be used to seal threaded connections.

**REQ-LS-0910:** For the Keck I laser system removable connections shall be made with Parker Hannifin series FS quick disconnect fittings. The instrument supply coupler shall be male and the return coupler shall be female.

**REQ-LS-0911:** The GS laser system coolant supply and return connections shall be Parker Hannifin series FS quick disconnect fittings

**REQ-LS-0912:** Zinc coated parts shall not be used for any components that will come into contact with the coolant supply.

### 5.3.13 Coolant Supply Conditions

**REQ-LS-0913:** The laser system shall be designed for proper operation with a coolant supply meeting the conditions given in Table 23. When supplied with the coolant conditions given in Table 23 all laser system enclosures shall not exceed the dissipation limits given in Table 11.

| *Parameter* | *Requirement Number* | *Min.* | *Typ.* | *Max.* | *Units* | *Notes* |
|---|---|---|---|---|---|---|
| Coolant fluid | | | | | | |
| GS | REQ-LS-0682 | N/A | N/A | N/A | N/A | 1 |
| Keck I | REQ-LS-0683 | N/A | N/A | N/A | N/A | 2 |
| Supply temperature | | | | | | |
| GS | REQ-LS-0684 | -5 | 0 | +5 | ºC | 3 |
| Keck I | REQ-LS-0687 | -10 | 0 | +3 | ºC | 4 |
| Coolant pressure | REQ-LS-0679 | - | 45 | 100 | psig | 5 |
| Flow rate | | | | | | |
| GS | REQ-LS-0694 | - | - | 40 | l/min | |
| Keck I | REQ-LS-0688 | - | - | 20 | l/min | |
| Pressure drop | | | | | | |
| GS | REQ-LS-0695 | - | 6 | 8 | psi | |
| Keck I | REQ-LS-0689 | - | 6 | 8 | psi | |

**Table 23: Coolant Supply Conditions**

Notes:

1. 40% by volume Dowtherm SR1 with water.
2. 50% water and 50% ethylene glycol. The freezing point is – 37 ºC. The mixture has a specific heat of 3198 J/kg ºK (0.764 Btu/lb ºR), and the density is 1067 kg/$m^3$ (66.5 lb/$ft^3$). Coolant must include a corrosion inhibitor.
3. Seasonally dependent.
4. The coolant temperature set point is 3 ºC below the dome ambient air temperature.
5. All laser system cooling system plumbing should be able to withstand a maximum pressure of 100 psig in the event of system pressure regulation failure.

## 5.4 Electrical/Electronic

### 5.4.1.1 Electromagnetic Compatibility

The design of existing system structures, subsystems, and their equipment utilize materials, material surface treatments, construction methods, fastener types/ spacing, component placement, cable routing and isolation, electrical bonding and grounding, and shielding provisions to control and minimize electromagnetic interactions and to attenuate interference.

**REQ-LS-0860:** New electrical/electro-mechanical assemblies shall be designed to provide a minimum attenuation of 60 dB to electromagnetic fields at frequencies between 30 MHz and 1 GHz. New system hardware designs shall implement the guidelines and principals contained within MIL-STD-461E "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment", MIL-HDBK-454A "General Guidelines for Electronic Equipment", and MIL-HDBK-1857 "Grounding, Bonding and Shielding Design Practices".

### 5.4.1.2 AC Line Connections

**REQ-LS-0880:** All AC line connected parts shall be enclosed so as to prevent accidental contact with live parts. All external AC line connections shall utilize UL listed connectors and cables.

**REQ-LS-0881:** All power input connectors shall have an adjacent label indicating the voltage, frequency and current rating for which the equipment is designed.

### 5.4.1.3 Power Supply Architecture

**REQ-LS-0879:** The laser system shall be designed so that all subsystems and components are supplied with power from either the laser system AC mains power input (see §5.6.6) with suitable internal distribution and protection (see §4.3.2.2), or from a 120 Vac or 208 Vac input power conversion system (such as a DC output power supply) supplied from the AC mains power input via suitable internal distribution and protection (see §4.3.2.2). In any case, except for configuration memory or real time clock back-up in computer systems or the operating hours meter as described in REQ-LS-0440, no batteries of any kind, rechargeable or otherwise, shall be used in the laser system.

### 5.4.1.4 Covers

**REQ-LS-0882:** Removable covers that permit access to circuits with voltages in excess of 36 volts rms ac or 30 Vdc shall be marked with a warning label.

**REQ-LS-0883:** Removable covers that permit access to circuits of less than 36 volts rms ac or 30 Vdc that are capable of fault currents in excess of 2 amperes shall be marked with a warning label.

### 5.4.1.5 Wiring

**REQ-LS-0884:** Internal wiring of 120/208/240 Vac circuits shall use a listed UL style of appliance wiring material. Where wiring is not subjected to movement or damage, any UL listed style including style 1371 (MIL-W-16878/4) suitable for the purpose may be employed. Where wiring may be subjected to movement, such as in service loops between internal subsystems, additional insulation shall be provided to protect the wire from damage. Teflon insulated wire shall be secured or tied in a manner that does not cause cold flow of the insulation. Vendor will also follow guideline 69 "INTERNAL WIRING PRACTICES" of MIL-HDBK-454A "General Guidelines for Electronic Equipment".

**REQ-LS-0885:** The insulation color of internal wiring and the conductors of multi-conductor cable for AC power wiring shall conform to the requirements of the National Electric Code. The insulation of neutral (grounded) conductors shall be white or gray in color. Neutral conductors shall be the same size as phase

conductors except in cases where two or more phases are provided and harmonic currents are expected, in which case the neutral conductors shall be 125% of the size of the phase conductors.

**REQ-LS-0886:** The insulation of grounding conductors (protective or earth ground) shall be green or green with a yellow stripe.

**REQ-LS-0887:** Grounding conductors shall be the same size as the phase conductors.

**REQ-LS-0888:** AC power phase, neutral and ground conductors shall be sized using table 310.17 of the National Electric Code for individual conductors used for internal wiring and table 310-16 for external connecting cables. For cables with more than three conductors used for AC power wiring the derating adjustment factors of table 310.15(B)(2)(a) shall be applied.

#### 5.4.1.6 Grounding and Shielding

**REQ-LS-0889:** The enclosures of AC line connected components shall be grounded. Grounding conductors shall be continuous and bonded to the enclosure in at least one point. The grounding point shall be specifically provided for the purpose and shall not be a screw or nut used for mounting components or covers. Any paint or surface treatment that acts as an insulator shall be removed in order to ensure a good electrical contact for the ground connection.

**REQ-LS-0890:** This requirement deleted.

#### 5.4.1.7 Terminations

**REQ-LS-0891:** Crimp terminals and compression screw terminals shall not be used to terminate more than the number of conductors specifically approved for the terminal. All crimp terminals and screw terminals used for AC line connected wiring must be UL recognized components. All crimp terminations shall be performed using the manufacturer's tooling in accord with the manufacturer's instructions.

#### 5.4.1.8 Printed Circuit Boards

**REQ-LS-0892:** All removable plug-in printed circuit boards shall be equipped with positive retention features. Extractors shall be provided for all circuit boards where high insertion and withdrawal forces are expected. Card extenders shall be provided for all plug-in printed circuit boards that do not utilize industry standard bus configurations with readily available card extenders.

#### 5.4.1.9 Wiring and Interconnections

##### 5.4.1.9.1 Connector and Cable Mounting

**REQ-LS-0893:** Cable and wiring strain relieves shall be designed so that strain relief and wiring integrity is not compromised by opening access doors or removing service access covers.

**REQ-LS-0894:** Connectors shall not be mounted on service access covers or on access doors.

##### 5.4.1.9.2 Cable and Wire Routing

**REQ-LS-0895:** Cables and wiring shall be routed so that they do not interfere with the optical path of the laser system. Cables and wiring must be routed so that full travel of moving or adjustable parts is not affected and does not place a strain on the mounting or connections of any cables or wiring. Service loops shall be provided when necessary, but all cables shall be routed neatly and secured at regular intervals with wire ties or lacing cord.

#### 5.4.1.9.3 Interconnections

**REQ-LS-0815:** External interconnections of low voltage AC and DC circuits shall be shielded whenever there is a reasonable possibility that those interconnections will be subject to electromagnetic interference or unwanted coupling.

**REQ-LS-0816:** This requirement deleted.

**REQ-LS-0817:** Wherever possible**,** cable shields should be electrically continuous with the connector housing, and WMKO prefers that no ground pigtails or other wire connections separate from the connector housing be used. In cases where the design requires different practices, those design requirements should be discussed with WMKO.

**REQ-LS-0795:** All external, interconnecting cables shall be uniquely identified and labeled. The labeling and identification shall be in a clearly visible and non-removable form. This identification scheme shall be identical to that used in the system documentation. Identification of cables by color-coding is appropriate and encouraged but is not a substitute for clear labeling.

#### 5.4.1.9.4 Data Communications Formats

**REQ-LS-0818:** Data communications between the laser system and remotely located computers shall be 100-base TX local area network (LAN) communications.

**REQ-LS-0819:** Where network communications are required between components in the laser system including communications with the laser control system computer such communications shall be via a private 100-base TX LAN (the laser system private network).

**REQ-LS-0820:** All 100-base TX LAN communications shall conform to the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.3U revision 95 "Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications: Mac Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mb/S Operation (Version 5.0)".

### 5.4.2 Connector Selection

**REQ-LS-0790:** Where specific connector types are required by the ICDs (see §2.1) those connector types will be used as required by the ICDs. Identically sized and sexed connectors on the same unit shall be keyed to prevent them from being interchanged.

**REQ-LS-0792:** Connectors, connector backshells and panel mounted connectors shall have conductive finishes compatible with the shielding and grounding requirements of §5.4.1.6 and the shield termination requirements of §5.4.1.9.3.

## 5.5 Servo Controls

### 5.5.1 Motion Control Servo Controls

All motion control systems used to implement motion control servo controls in the laser system shall meet the requirements given in REQ-LS-0850 through REQ-LS-0854.

**REQ-LS-0850:** No part of any laser system mechanism shall move when AC mains power is applied to or removed from the laser system with the exception of piezoelectric transducer (PZT) devices and safety devices. Any motion that does occur shall not create a hazard to personnel. The laser system motion control hardware shall inhibit all motion during a power on/reset.

**REQ-LS-0851:** If closed loop or servo systems are used for motion control the motion control system shall be designed so that loss of the encoder or disconnection of the motor cannot result in a "wind up" of the

servo position command signal. Software features shall be implemented to inhibit motion when the position error measured by the servo controller exceeds the smallest reasonable margin that reflects all of the expected operating conditions.

**REQ-LS-0852:** Limit switches shall be closed when not actuated (N.C. contacts). Motion control software shall be designed so that a disconnected limit switch will appear to be active, inhibiting further motion towards that limit. Motion control software shall also be designed so that movement away from an active limit switch is restricted to a reasonable distance past the limit switch actuation point after which motion is stopped and an error indicated due to the apparent failure of the limit switch to open.

As a **goal,** position encoders shall include a status loop through the connections to the encoder so that in the event of loss of the encoder connection (or intentional disconnection) all motion on the associated axis is inhibited.

**REQ-LS-0854:** Digital motion control systems are preferred and shall be used unless a performance or operating requirement cannot be met with a digital control system. For the GS laser system the vendor should note that AURA has used Delta Tau PMAC-VME motion-control cards in other on-telescope systems (such as the Mount Control System), and they may wish to use the same in order to limit the number of differing systems in use. The laser system vendor should also note that AURA recommends the use of Allan Bradley PLC5 for Programmable Logic Controllers.

### 5.5.2 All Servo Controls

All servo control loops, including those used for motion control systems shall meet the requirements given in REQ-LS-0855

**REQ-LS-0855:** Wherever possible all servo loops shall be provided with facilities that permit open loop operation. Where possible the selection of open loop or closed loop operation shall be accomplished by a software command.

**REQ-LS-0856**This requirement deleted.

**REQ-LS-0857**This requirement deleted.

### 5.5.3 Over Temperature Protection

**REQ-LS-0915:** Over temperature protection shall be provided in all laser system enclosures to protect the components from damage due to over heating due to a coolant supply failure.

**REQ-LS-0916:** Unless otherwise specified over temperature protection shall be accomplished by a thermal cut off device that removes all power from the components in the enclosure where the over temperature occurs. Reset of the thermal cutoff device will restore power to the laser system but restart of the laser system will require manual intervention.

## 5.6 Safety

### 5.6.1 Fail-safe Systems

**REQ-LS-0830:** Fail-safe implementations shall be used throughout the laser system for protection systems that are required to meet regulatory requirements and to protect the safety of personnel and equipment.

**REQ-LS-0831:** Redundant interlock switches shall be provided for all access doors of the laser bench and laser electronics enclosures.

**REQ-LS-0835:** This requirement deleted.

**REQ-LS-0840:** This requirement deleted.

### 5.6.2 Laser Shutters

**REQ-LS-0842:** The laser shutters described in §4.1.1 shall be held closed by a positive acting mechanical device and held open by an electrically energized device. In the event of a power failure the laser shutters shall close.

**REQ-LS-0844:** The laser shutters described in §4.1.1 shall be equipped with position sensing switches (electro-mechanical or optical) that shall positively indicate the position of the shutter to the laser system control circuits for monitoring by the laser control system software.

**REQ-LS-0843:** The laser system shall be equipped with a "laser shutter manual switch" located on the laser bench enclosure. This switch shall provide two positions: the "Disable" position shall keep the laser shutter closed and prevent opening of the laser shutter via software at all times. The "Enable" position shall enable normal laser shutter operation.

### 5.6.3 Standards and Regulatory Compliance Requirements

#### 5.6.3.1 General Safety

**REQ-LS-0925:** The laser system shall comply in all respects with the applicable requirements of the Occupational Safety and Health Administration (OSHA) as established by CFR 29 Part 1910 "Occupational Safety And Health Standards", particularly subpart O, section 1910.212 and subpart S sections 1910.302 through 1910.304.

**REQ-LS-0926:** The laser system delivered to WMKO shall conform to the requirements of the National Electric Code (NEC). The applicable local electric code is the Hawaii County Code 1983, 1995 Edition. This code adopts the National Electric Code in its entirety and there are no additional special requirements applicable to the locations where the laser system will be installed or operated. Vendor's attention is specifically directed to the following articles of the NEC:

Article 110 Requirements for Electrical Insulation
Article 200 Use and Identification of Grounded Conductors
Article 250 Grounding
Article 300 Wiring Methods
Article 310 Conductors for General Wiring
Article 312 Cabinets, Cutout Boxes, and Meter Socket Enclosures
Article 400 Flexible Cords and Cables
Article 404 Switches
Article 647 Sensitive Electronic Equipment

Vendor's attention is also directed to the fact that MIL-STD-464 "Electromagnetic Environmental Effects, Requirements for Systems" lists in section A2.2 the NEC as an "applicable non-government publication".

**REQ-LS-0927:** The laser system shall conform to the applicable safety requirements of MIL-STD-464 "Electromagnetic Environmental Effects, Requirements for Systems". Vendor will also follow guideline 1 "SAFETY DESIGN CRITERIA - PERSONNEL HAZARDS" of MIL-HDBK-454A "General Guidelines for Electronic Equipment".

#### 5.6.3.2 Laser Safety

The laser system vendor shall be responsible for ensuring that the laser systems comply with all applicable laser safety guidelines in effect in the United States and at the location where the laser is installed. These include but may not be limited to the standards and guidelines listed in REQ-LS-0928 through REQ-LS-0931.

**REQ-LS-0928:** The laser system shall comply with the laser safety guidelines given in OSHA instructional directive STD 01-05-001 "Guidelines for Laser Safety and Hazard Assessment".

**REQ-LS-0929:** The laser system shall comply with the requirements of the FDA as established by CFR 21 Part 1040 "Performance Standards for Light-Emitting Products" dated April 1, 2004.

**REQ-LS-0930:** The laser system shall comply with ANSI standard Z136.1-2000 "American National Standard for the Safe Use of Lasers".

**REQ-LS-0931:** The laser system vendor shall be responsible for the submission of any applicable reports to the Center for Devices and Radiological Health (CDRH). The laser system vendor shall be responsible for obtaining any regulatory approvals or waivers that may be required prior to delivery of the laser systems to Gemini and WMKO.

#### 5.6.3.3 Safety Keys

The laser system shall be provided with the safety key systems described in REQ-LS-0932 and REQ-LS-0935.

**REQ-LS-0932:** There shall be a start-up key lock operated switch located on one of the laser system enclosures that must be turned "on" before the start-up procedure required in REQ-LS-0305 can take place. The laser system shall not begin the start-up procedure unless the start-up key lock operated switch is turned to the "on" position.

**REQ-LS-0935:** There shall be a low power software operated switch. When this switch is placed in the "low power only" position the laser system shall operate in LOW POWER mode only (see Table 6 requirements REQ-LS-0131 and REQ-LS-0132). When in the switch is placed in the "low power only" position the laser control system software shall prevent local and remote software systems from commanding and achieving high power mode, and all power down or safety shut down modes shall continue to operate. The laser control system software shall provide a prominent display of the state of this switch on the laser control system software display. When the switch is in "normal mode" the laser control system software shall accept all laser operation modes.

### 5.6.4 Interlocks

**REQ-LS-0940:** Removable panels or access doors that expose voltages in excess of 220 Vac or 500 Vdc should be equipped with defeatable interlock switches that remove all voltages in excess of 36 Vac or Vdc from all exposed connections and terminals.

#### 5.6.4.1 Laser System Internal Interlocks

**REQ-LS-0942:** The laser system shall use internal interlocks to ensure safe operation of all laser system hardware components. For instance, the laser operation may involve some sequences of actions that have to be taken in a pre-defined order for laser hardware not to be damaged. In such cases, there must be software interlocks to ensure that those sequences of actions are performed in the correct order. Such interlocks shall be implemented within the laser system and are expected to be invisible to the end-user during normal laser operation.

**REQ-LS-0945:** The laser system shall use internal interlocks to ensure personnel safety in all activities involving the laser system. Personnel safety interlocks shall have only hardwired electromechanical components. Operation of personnel safety interlocks shall not depend on the transmission of commands over a communication network or link.

**REQ-LS-0948:** Laser system internal personnel safety interlocks associated with removable covers, doors, partitions or shields intended to safeguard personnel from laser radiation shall when activated immediately cause all laser emissions within the laser system to cease.

**REQ-LS-0990:** This requirement deleted.

**REQ-LS-0992:** This requirement deleted.

#### 5.6.4.2 Interface with the Laser Interlock System (LIS)

**REQ-LS-0950:** The GS laser system shall be interfaced with the Gemini Laser Interlock System (LIS) as described in referenced document 3 (see §2.1). The Gemini LIS is a subsystem of the Gemini Interlock System and is described in appendix D. Referenced document 3 is the LIS to GS laser system interface control document (ICD). Please refer to this ICD for complete details on the required Gemini South laser system input/output signals to/from the LIS, and the corresponding electronic interface between those two systems.

**REQ-LS-0951:** The Keck I laser system shall be interfaced with the WMKO laser safety system. WMKO will accept the Keck I laser system with interfaces as provided for the Gemini LIS on the GS laser and will do the work necessary to interface the Gemini LIS compatible laser system interfaces to the WMKO laser safety system.

### 5.6.5 Emergency Stops

#### 5.6.5.1 Laser System Emergency Stop

**REQ-LS-0952:** At least one large mushroom style pushbutton switch, the "laser system emergency stop" switch shall be provided on the exterior of the laser electronics enclosure in a readily accessible location. When this switch is activated the laser system emergency shutdown described in REQ-LS-0328 shall be initiated. Once activated the switch shall lock in the activated position and shall require deliberate action to reset the switch to the inactive position.

**REQ-LS-0953:** The mushroom style pushbutton switch provided on the laser systems shall be red in color.

**REQ-LS-0960:** Reset of the laser system emergency stop switch must not initiate a laser system start-up.

#### 5.6.5.2 Telescope Emergency Stop

**REQ-LS-0965:** A 24 Vdc input shall be provided by the laser system for connection to the telescope or observatory emergency stop circuit. The laser system shall not perform a start-up procedure unless this input is energized. When this input is de-energized the laser system shall immediately initiate the emergency shutdown described in REQ-LS-0328.

**REQ-LS-0970:** Reset (re-energization) of the telescope or observatory emergency stop circuit must not initiate a laser system start-up.

### 5.6.6 Laser System AC Mains Power Supply

**REQ-LS-0975:** The laser system shall have a single source of AC mains power input or shall be safety labeled to indicate multiple sources of AC mains power input.

**REQ-LS-0976:** The laser system shall be equipped with a manually operated main power disconnect switch on the exterior of the laser electronics enclosure in a readily accessible location.

**REQ-LS-0977:** The position of the main power disconnect switch main power shall be positively indicated at all times, even when any access doors or covers over the switch are opened or removed.

**REQ-LS-0978:** There shall be no exposed electrically live parts when the main power disconnect switch is in the open position, even when any external access doors or covers over the switch are opened or removed.

### 5.6.7 Fire Protection

**REQ-LS-0979:** This requirement deleted.

**REQ-LS-0980:** Foams used for insulation must be flame retardant and of the closed cell variety.

## 5.7 Software

### 5.7.1 Overview

The laser control system software requirements are based on assumptions about the hardware and software architecture of the laser system. These assumptions can be understood by referring to the block diagram shown in Figure 2. In this block diagram the laser system is shown as two major components, a laser control system computer, and the laser hardware. The laser control system computer is the primary control computer for operation of the laser hardware. Interfaces are provided between the laser control system computer and the laser hardware in order to allow the laser control system computer to control the laser hardware via analog and digital signals. The laser control computer also provides the data acquisition hardware needed to support measurement and monitoring of laser system performance.

The laser control system computer runs the laser control software, which includes a server module that communicates via a command and status interface (CSI) with other computer systems external to the laser system in order to perform the control and monitoring functions described in this requirements document.

The laser control system computer communicates with other computer systems external to the laser system via control LAN connection as described in §5.4.1.9.4

Also shown in Figure 2 is the interlock interface between the laser hardware and the Gemini LIS or WMKO laser safety system as described in §5.6.4.2.

The laser control system software CSI will also be used to provide an EPICS interface to the Gemini or WMKO control system software. The Gemini or WMKO control system software will be written using the EPICS software package and will be used to implement remote control of the laser system via a TCP/IP socket connection. The portion of the Gemini control system software that interfaces with the laser system is called the Laser EPICS Interface (LEI).

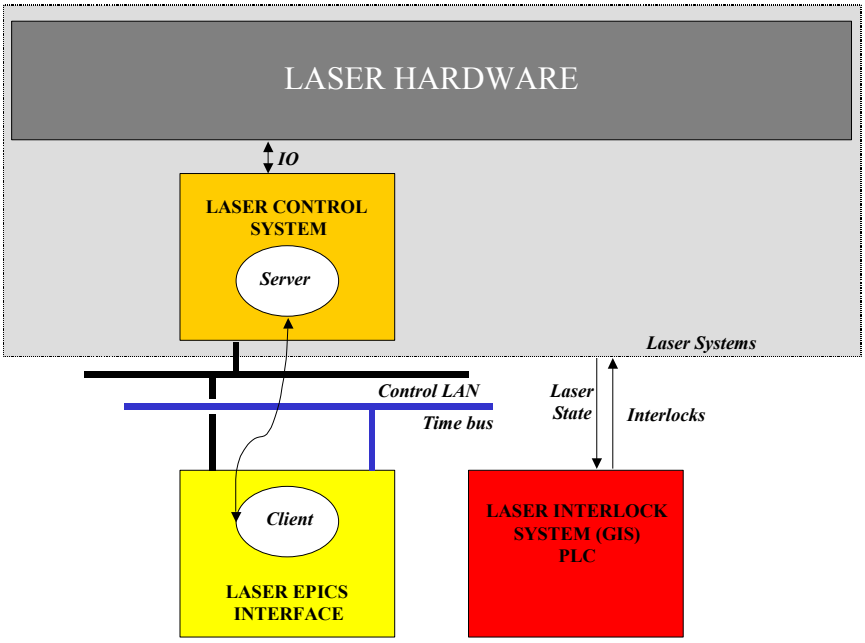


**Figure 2: Laser System External Interfaces**

### 5.7.2 Scope

**REQ-LS-1100:** The scope of the software to be provided by the laser system vendor is the software required to:

1. Control all laser system hardware.
2. Implement all software servo control loops within the laser system.
3. Implement all safety related software functions required for the laser system.
4. Provide a stand-alone laser control system and user interface.
5. Provide the measurement and monitoring functions required for the laser system.
6. Provide the server capable of supporting multiple TCP/IP socket connections for control of the laser control system software via a CSI.

The software to be provided by the laser system vendor does not include the LEI or any other part of the Gemini or WMKO control system software.

### 5.7.3 Hardware Components

**REQ-LS-1101:** The laser system vendor shall supply all required hardware components to implement the laser control system computer and all interfaces between the laser control system computer and the laser hardware. If devices internal to the laser system require LAN communications these shall be implemented as described in §5.4.1.9.4.

**REQ-LS-1102:** The laser system vendor shall supply all required hardware to implement the external interfaces between the laser system and external systems. These consist of the following interfaces:

1. Control LAN implemented as described in §5.4.1.9.4.
2. LIS interfaces as described in §5.6.4.2.

#### 5.7.3.1 Laser Control System Computer Hardware Implementation

Gemini and WMKO would prefer that the laser control system computer be implemented with plug-in circuit cards using a card and back plane arrangement with plug-in cards not larger than 6U form factor. WMKO prefers that the backplane and circuit cards conform to the electrical requirements of the American National Standards Institute (ANSI) VME64 standard, ANSI/VITA 1-1994 (R2002) and the standard for VME64 Extensions, ANSI/VITA 1.1-1997 (R2003). Other industrial grade bus architectures with recognized standards that are adequately supported by a wide range of manufacturers (such as Compact PCI) are also acceptable.

### 5.7.4 Software Architecture

**REQ-LS-1103:** The laser control system software shall provide a server module capable of supporting multiple TCP/IP socket connections for control of the laser control system software via a CSI. The server TCP/IP socket connections and CSI shall be designed in accord with the requirements of referenced document 5 (see §2.1).

**REQ-LS-1104:** The laser system vendor shall design the CSI. Gemini and WMKO will design the EPICS database to be used for communication with the laser control system server software CSI. The vendor shall cooperate with Gemini and WMKO in the design of the CSI in order to maximize the compatibility of the CSI with the EPICS database. The CSI shall be substantially the same as the CSI for the GN laser system. AURA shall approve any changes to the CSI prior to implementation.

**REQ-LS-1105:** The laser control system software shall implement a single process thread running on the laser control system computer that will perform all critical laser system operating and control functions including the laser system control functions described in §4.5.3 and §4.5.5. The same process thread shall implement the software portions (if any) of the laser system internal interlocks described in §5.6.4.1. The

same process thread shall implement the laser control system server module that provides the CSI described in REQ-LS-1103.

**REQ-LS-1106:** All laser control system software shall be implemented in accordance with the National Instruments Corporation document "LabVIEW™ Development Guidelines", April 2003 edition, National Instruments Part Number 321393D-01 and where applicable, referenced documents 13 and 14.

**REQ-LS-1107:** All laser control system software shall employ current best practices in modular design.

**REQ-LS-1108:** When all of the software available in the laser system is running concurrently on the laser control system computer the loading of the laser control system computer processor or processors shall not exceed an average of 50% of the total processor loading for the laser control system computer over any time interval.

### 5.7.5 Laser Control System Software Interfaces

#### 5.7.5.1 EPICS

**REQ-LS-1110:** The laser control system server module running on the laser control system computer shall be used to control the laser system using the CSI described in §5.7.4. A TCP/IP socket connection to this CSI shall control the laser system via the Gemini or WMKO control system software written using the EPICS software package.

**REQ-LS-1109:** The laser control system interface to the Gemini or WMKO Laser EPICS Interface (LEI) shall be in accordance with the requirements presented in referenced document 9 (see §2.1).

#### 5.7.5.2 User

**REQ-LS-1111:** The laser control system software shall provide a graphical user interface software package (GUI), the laser control system software GUI, to provide stand-alone control of the laser system. This software shall support all of the required software sequences, commands, measurement and monitoring facilities described by this requirements document in §5.7.6 and elsewhere in this document. The GUI shall also provide facilities for invocation of the engineering GUI described in §5.5.2,. The laser control system computer and software shall be capable of remote operation via the control LAN using a customer provided Belkin Corporation Remote IP Console, Belkin part number F1DE101G or equivalent.

**REQ-LS-1112:** The laser control system software shall provide an engineering GUI for the laser system. The engineering GUI shall enable the laser system user to monitor and modify all the parameters and data appropriate to safe operation and maintenance of the laser system. These parameters shall include but are not limited to output 589 power, laser diode current, laser diode temperatures, laser diode output power, laser bench temperatures, etalon temperatures, coolant temperatures, dew point temperatures, SFG temperature, faults and warnings. This GUI shall be designed for execution on the laser control system computer or via the remote operation facilities described in REQ-LS-1111.

**REQ-LS-1113:** This requirement deleted.

**REQ-LS-1114:** The laser control system software GUI and the engineering GUI shall use the commands described in §5.7.6.2 to implement the GUI control actions. The laser control system software GUI and the engineering GUI shall implement handshaking and time outs to ensure that the status of all commands is known and to prevent lock up or crashing of the GUI due to failures or errors in the laser control system software.

**REQ-LS-1115:** The laser control system software GUI and the engineering GUI shall provide a prominent display for error and warning messages arising from operating sequences and commands initiated by the GUI.

### 5.7.6 Detailed Laser Control System Software Requirements

Unless noted otherwise all of the requirements in this section apply to the laser control system software CSI that is used to support the laser control system software GUI, the engineering GUI and the laser control system EPICS interface.

#### 5.7.6.1 Configuration

**REQ-LS-1145:** For the GS laser system the laser control system software shall identify the five GS laser beams as *Beam 1*, *Beam 2*, *Beam 3*, *Beam 4* and *Beam 5*. All software commands described in §5.7.6.2 that may be applied to one or more lasers shall use these laser beam designations. The laser control system software shall provide a user definable configuration file that shall define the correspondence between the five physical laser output beams in the GS laser system and the software labels.

**REQ-LS-1146:** When a laser system is configured with a single output beam the laser control system software shall conceal all displays and functions related to hardware not implemented in the laser system.

#### 5.7.6.2 Commands

**REQ-LS-1147:** For all commands implemented by the laser control system software the laser control system software shall, upon receipt of a command via the CSI, validate and either *accept* or *reject* each command. Validation shall include, but is not limited to, checking of the command format and the values of the parameters (if any) sent with the command. The status of all commands shall be reported via the CSI. The status reported when a command is rejected shall include a clearly worded error message describing the reason the command was rejected.

**REQ-LS-1148:** All commands implemented by the laser control system software and all functions to support transfer of data as described in §5.7.6.3 shall either provide an immediate status reply (synchronous commands) or the commands shall use a hand shaking mechanism such as a notify or callback (asynchronous commands) to return status at a later time.

**REQ-LS-1149:** This requirement deleted.

**REQ-LS-1150:** This requirement deleted.

**REQ-LS-1155:** The laser control system software shall automatically initialize all program variables when the laser control system software is first executed. As required by REQ-LS-0300 all user configurable parameters provided by the laser control system software shall be initialized from configuration files.

**REQ-LS-1156:** The laser control system computer shall be configured to automatically run the laser control system computer operating system software at power on or after a hardware reset or software reboot. The laser control system computer operating system shall be configured to permit a properly authorized user to access the system and start execution of the laser control system software.

**REQ-LS-1160:** The laser control system computer operating system software shall provide features to support the initiation of a software reboot using a customer supplied remote IP console as described in REQ-LS-1111.

**REQ-LS-1125:** The laser control system software shall provide a single command to run the start-up sequence described in §4.5.3.

**REQ-LS-1126:** Each individual step of the sequence used to implement the start-up sequence shall be available for execution as a manual unchecked sequence through the laser control system software GUI.

**REQ_LS-1130:** This requirement deleted.

**REQ-LS-1131:** This requirement deleted.

**REQ-LS-1132:** Each of the available internal tests shall be available for execution through the laser control system software GUI.

**REQ-LS-1135:** The laser control system software shall provide a single command to run the normal shutdown sequence described in §4.5.5.1.

**REQ-LS-1136:** Each individual step of the sequence used to implement the shutdown sequence shall be available for execution as a manual unchecked sequence through the laser control system software GUI.

**REQ-LS-1140:** The laser control system software shall provide a single command to run the emergency shutdown sequence described in §4.5.5.2.

**REQ-LS-1141:** Each individual step of the sequence used to implement the emergency shutdown sequence shall be available for execution as a manual unchecked sequence through the laser control system software GUI.

**REQ-LS-1142:** Where required software interlocks shall be provided within the laser control system software to ensure that individual sequence steps are executed in a safe order as required in §5.6.4.1.

**REQ-LS-1165:** The laser control system software shall provide a command to control the laser shutter as described in §4.1.1.

**REQ-LS-1170:** If the goal described in §3.1.3.1 is achieved the laser control system software shall provide a command to permit adjustment of the total output power of the laser system.

**REQ-LS-1171**This requirement deleted.

**REQ-LS-1173:** The laser control system software shall provide a command to select the power settings required by REQ-LS-0130, REQ-LS-0131 and REQ-LS-0132. When the software operated low power switch required by REQ-LS-0935 is placed in the "low power only" position the power setting command shall be rejected and the laser control system software shall be inhibited from selecting the FULL POWER mode.

**REQ-LS-1174:** The laser control system software shall provide a command to step the central frequency of all output laser beams using the tunability required by REQ-LS-0150 and REQ-LS-0151. If the goal described in §3.1.3.4 is achieved the laser control system software shall support the maximum tuning rate supported by the laser system tuning capability.

**REQ-LS-1175:** The laser control system software shall provide a command to shift the central frequency of all output laser beams using the tunability required by REQ-LS-0155 and REQ-LS-0160. If the goal described in §3.1.3.4 is achieved the laser control system software shall support the maximum tuning rate supported by the laser system tuning capability.

**REQ-LS-1176:** This requirement deleted.

**REQ-LS-1178:** The laser control system software shall provide a command to reset the warning or fault states reported by laser control system software as in REQ-LS-1250. This command shall only reset warning or fault states for which the generating conditions are no longer present.

**REQ-LS-1195:** All other laser control system software commands implemented by the laser vendor shall be available for control via the CSI described in §5.7.4 in a manner that complies with REQ-LS-1147.

#### 5.7.6.3 Measurement and Monitoring Facilities

**REQ-LS-1200:** The laser control system software CSI shall provide functions to permit transfer of all of the data acquired by the data acquisition system controlled by, and preferably incorporated in, the laser control system computer from the measurement and monitoring capabilities required in §4.1.2 and §4.3. In addition, laser control system software CSI shall provide functions to permit transfer of all of the data acquired from the additional laser system vendor provided monitoring facilities as required to verify the state of all internal sensors, interlocks and fault sensors provided as part of the laser system. The status of rejected commands (REQ-LS-1147) shall also be written to the log file.

**REQ-LS-1210:** The laser control system software CSI shall provide support for change of state notification for any or all of the data acquired by the data acquisition system controlled by, and preferably incorporated in, the laser control system computer from the measurement and monitoring capabilities required in §4.1.2, §4.3 and all of the data acquired from the additional laser system vendor provided monitoring facilities as required to verify the state of all internal sensors, interlocks and fault sensors provided as part of the laser system (see REQ-LS-0410).

**REQ-LS-1212:** The laser control system software CSI shall provide functions to permit transfer of state information for the position of the laser shutter as described in §4.1.1.

**REQ-LS-1220:** This requirement deleted.

**REQ-LS-1230:** The laser control system software CSI shall provide a "heartbeat" variable that updates at a rate of 1 Hz.

**REQ-LS-1240:** The laser control system software CSI shall provide a connection status message for use with the EPICS interface that updates at a rate of 1 Hz.

**REQ-LS-1250:** The laser control system software CSI shall provide functions to permit transfer of status information regarding warning or fault conditions present in the laser system due to any condition in the laser system that may affect the proper operation of the laser system with respect to performance and operating requirements and safety requirements. This shall include but not be limited to the over temperature status monitoring of the coolant temperature monitoring of §4.3.1 and the interlocks of §5.6.1 and §5.6.4.

**REQ-LS-1260:** The laser control system software CSI shall continue to report all warning or fault conditions described in REQ-LS-1250 until a command is issued to reset the warning or fault states as described in REQ-LS-1178.

**REQ-LS-1290:** The laser control system software shall provide for user selection of a log file name and location that shall be used to store all of the data acquired by the data acquisition system controlled by, and preferably incorporated in, the laser control system computer from the measurement and monitoring capabilities required in §4.1.2, §4.3 and all of the data acquired by the additional laser system vendor provided monitoring facilities as required to verify the state of all internal sensors, interlocks and fault sensors provided as part of the laser system. The format of the log file shall be approved by AURA.

As a **goal**, the laser control system software shall keep a software record of the total laser system power on hours and the total laser system laser operating hours. This value shall be stored in the log file every 0.1 hours.

**REQ-LS-1292:** All log file entries shall be time stamped using the time values provided by the Laser EPICS interface described in REQ-LS-1109.

**REQ-LS-1294:** The laser control system software GUI shall provide a console window display capable of displaying all of the messages written to the log file as they are written to the log file.

## 5.8 Interfaces

### 5.8.1 Interface requirements

#### 5.8.1.1 Interface with the Telescope

**REQ-LS-0612:** The GS laser system shall be mounted on the Nasmyth Platform of the GS telescope in a manner that is fully compatible with the laser system to BTO interface requirements given in §3.1.2.3.1 and §5.8.1.2. The laser system may be split as shown in drawing 89-GP-3170-0123 into the following subsystems: (1) the laser bench enclosure(s), containing the laser optical bench(s), and (2) the laser electronics enclosure(s) mounted adjacent to the optical bench(s).

**REQ-LS-0620:** For the GS laser system the laser system vendor shall package the laser system optical bench(s) so as to interface with the telescope as described in referenced document 1 (see §2.1) and shown in drawing numbers 89-GP-3110-0010 and 89-GP-3110-0011. The laser system shall comply with all mechanical interfaces described in referenced document 1. Referenced document 1 is the ICD for the interfaces between the laser system and the GS telescope.

**REQ-LS-0622:** The Keck I laser system shall be mounted in the laser service enclosure on the Nasmyth Platform of the Keck I telescope as shown in drawing 1750-C3001. The laser system may be split as shown in drawing 1750-C3001 into the following subsystems: (1) the laser bench enclosure, containing the laser optical bench, and (2) the laser electronics enclosure mounted adjacent to the optical bench.

**REQ-LS-0624:** For the Keck I laser system vendor shall package the laser system optical bench so as to interface with the telescope as described in referenced document 10 (see §2.1) and shown in drawing number 1750-C3001. The laser system shall comply with all mechanical interfaces described in referenced document 10. Referenced document 10 is the ICD for the interfaces between the laser system and the Keck I telescope.

#### 5.8.1.2 Interface with the BTO

**REQ-LS-0625:** All opto-mechanical interfaces between the GS laser system and the GS BTO are described in referenced document 2 and illustrated in drawing numbers 89-GP-3110-0010 and 89-GP-3110-0011. The GS laser system shall comply with all such interfaces so as to ensure that the required output location and direction of propagation of all five laser output beams are as described in §3.1.2.3.1.

**REQ-LS-0626:** For the Keck I laser system vendor shall specify the laser beam output location and direction of propagation consistent with requirements REQ-LS-0622 and REQ-LS-0624.

# 6 RELIABILITY REQUIREMENTS

## 6.1 Lifetime

**REQ-LS-0445:** The laser systems will be in operation at least 2200 hours per year, and no more than 2700 hours per year, for a period of at least 3 years. The laser system shall be designed to operate for a total of at least 6600 hours over the course of 3 years while meeting all the maintenance-related requirements presented in §8.

As a **goal**, the laser systems shall be designed to operate for a total of at least 2200 hours per year over the course of 10 years.

## 6.2 MTTR (Mean Time to Repair)

For the purposes of this section minor failures are defined as failures that can be repaired by a trained technician of average skill using commonly available tools. For the purposes of this section major failures are failures that require a laser specialist of advanced skill or a vendor service person to repair. Major failures may also be failures that require specialized test equipment for realignment or optimization after the repair is completed.

**REQ-LS-0448:** This requirement deleted.

**REQ-LS-0449:** This requirement deleted.

**REQ-LS-0450:** This requirement deleted.

**REQ-LS-0451:** The laser system shall be designed so that provided the required spare parts and supplies are on hand, minor failures can be repaired within 8 hours.

**REQ-LS-0452:** The laser system shall be designed so that, provided the required spare parts and supplies are on hand, major failures can be repaired within 4 days, not including travel time.

As a **goal**, the laser system shall be designed so that, provided the required spare parts and supplies are on hand, major failures can be repaired within 2 days, not including travel time.

## 6.3 This section deleted

## 6.4 Normal operation

**REQ-LS-0446:** Other than minor and major failures as covered in §6.2, the laser system shall need neither adjustment nor service during 12 consecutive hours of operation. During regular LGS AO observations at night, a non-laser specialist will remotely operate the laser system and it is imperative that the laser system performs reliably during the full 12 hours of a typical night of astronomical observations, from start-up before sunset to shutdown after dawn. Automatic recovery from faults requiring loss of laser output of less than 10 minutes duration are acceptable on a once per night basis.

# 7 SPARES REQUIREMENTS

**REQ-LS-0447:** This requirement deleted.

**REQ-LS-0453:** The laser system vendor shall certify to AURA that all purchased components used in the laser system are not in end of life status at the time of purchase.

# 8 SERVICE AND MAINTENANCE REQUIREMENTS

## 8.1 Design Considerations for Service and Maintenance

**REQ-LS-0454:** The laser system shall by design minimize the effort required to maintain the laser system in a state of readiness for regular operation. An acceptable level of effort is defined as not more than 8 hours of maintenance for every 150 hours (approximately 14 operating nights) of laser operation. A laser technician shall spend no more than a total of 24 hours per week in order to prepare the laser system for normal operation, assuming that the laser system is used every night of that week. The laser technician shall spend no more than an extra 16 hours per month to perform additional maintenance tasks.

**REQ-LS-0455:** The laser system shall by design minimize the effort required to perform regular maintenance tasks including but not limited to, cleaning of optics or replacement of limited lifetime or consumable components. AURA defines the acceptable level of effort for cleaning of optics as not more than 30 minutes per optic when performed by a trained technician of average skill using commonly available tools and any specialized tools provided by the laser vendor as part of the laser system deliverables.

**REQ-LS-0456:** The laser system shall be designed and constructed so that no major sub-assembly removal shall be required to access components needing regular maintenance, including but not limited to, cleaning or scheduled replacement.

**REQ-LS-0457:** The laser system shall be designed and constructed so that no more than minor realignment and optimization of the laser system performance shall be necessary after cleaning or replacement of one passive optic. AURA defines minor re-alignment and optimization as a procedure that takes no more than 60 minutes when performed by a trained technician of average skill using commonly available tools and any specialized tools provided by the laser vendor as part of the laser system deliverables.

**REQ-LS-0458:** As required in §5.3.1.3, all optical components in the laser system shall be protected from dust and contamination. Regular cleaning procedures, if required, shall not need to be performed more than once every 30 calendar days as long as the Class 10,000 clean room environment is maintained by AURA and WMKO. If the particulate count drops below Class 10,000 requirements during the 30 day period, CTI cannot guarantee the optics will not need cleaning.

**REQ-LS-0459:** As required in §5.3.9.1 modules and components that must be removed for service shall be provided with locating pins and other features as required to permit repeatable removal and replacement with a minimum of readjustment or realignment. All replaceable components shall be able to be removed and replaced (not including time for realignment and optimization) within 30 minutes by a trained technician of average skill using commonly available tools and any specialized tools provided by the laser vendor as part of the laser system deliverables.

**REQ-LS-0460:** This requirement deleted.

## 8.2 Servicing environment

**REQ-LS-0461:** The laser system vendor shall provide recommendations for the tools and equipment needed to perform regular maintenance and service on the laser system.

**REQ-LS-0462:** The laser system vendor shall provide recommendations with respect to the environmental conditions required to service the laser including work within the laser bench enclosure(s).

**REQ-LS-0463:** The laser system vendor shall provide recommendations with respect to the supplies required to perform regular maintenance and service on the laser system.

## 9 DOCUMENTATION REQUIREMENTS

Unless otherwise specified all documents should be provided in electronic form on CD or DVD ROM and printed in bound hardcopy form. The electronic form of documentation should be supplied in the Adobe® Portable Document Format (PDF) file format.

### 9.1 Manual

**REQ-LS-0470:** The laser system vendor shall supply a laser system manual. The laser system manual shall include all information and procedures needed to maintain and operate the laser system during its lifetime, including, but not limited to, the following:

1. System overview and design description, including details of laser design, optical design, mechanical design (including cooling system design), electrical design and software design. All design documents shall be supplied in revised form as required to reflect the delivered as-built laser systems.

2. User's manual, including but not limited to operating instructions.

3. Revised fabrication/procurement drawings, assembly drawings, specifications, schematics, printed wiring board drawings (PWBs), printed wiring assembly (PWAs) drawings, and PWB artwork that accurately depict the as-built condition of all of the components of the laser system. Drawings determined competition sensitive per Section 5(b)(3) of the Statement of Work will not be included in the manual but will be placed in escrow. All such drawings shall be detailed enough to allow fabrication of spare parts should the need arise. The as-built drawings may be in hardcopy form.

4. Deleted.

5. Routine maintenance and inspection procedures, as well as a maintenance schedule.

6. Alignment procedures.

7. Troubleshooting guide.

8. Minor repair procedures.

9. Acceptance Test Plan documents, test procedures and all performance data and results of acceptance testing.

10. Descriptions of all recommend spare parts and procedures for removal and replacement including written procedures and assembly drawings.

11. All manufacturer's manuals and documentation for COTS components.

12. All software design documents and related documents including, but not limited to software build and install procedures, source code per section 8(c) of the SOW, release description document, software design document, and software user's manual. All software design documents and related documents shall be supplied in revised form as required to reflect the delivered as-built laser systems.

### 9.2 Drawings

**REQ-LS-0472:** All laser system vendor supplied drawings shall conform to the following:

1. Drawings for optical components shall conform to ANSI/ASME standard Y14.18M-1986 "Optical Parts (Engineering Drawings and Related Documentation Practices)".

2. Mechanical drawings shall conform to ANSI Y14.5M-1994 (R1999) "Dimensioning and Tolerancing" and ASME standard Y14.100-2000 "Engineering Drawing Practices".

3. Each sheet shall conform to ANSI Y14.1-1995 (R2002), "Decimal Inch Drawing Sheet Size and Format". Drawing size shall be determined on an individual basis.

4. Each drawing shall have a title block with at least the following information:
   - Development group
   - Vendor drawing number
   - Customer drawing number
   - Title
   - Designer
   - Draftsman
   - Scale
   - Method for determining next higher assembly.

5. Deleted.

6. All drawings shall include parts and materials lists in accordance with ANSI Y14.34-2003, "Parts Lists, Data Lists, And Index Lists: Associated Lists". All items shall be identified with an item number or other label (with reference to the drawing number if one exists) for each part or component with all information required for procurement.

7. Assembly drawings shall include all relevant views required to clearly define the assembly including isometric views.

8. All detail drawings shall include all views, geometry, dimensions and feature controls required to duplicate the part in accordance with ANSI Y14.5M-1994 (R1999) "Dimensioning and Tolerancing".

9. Multi and sectional view drawings shall be developed in accordance with ANSI Y14.3M-1994 "Multi and Sectional View Drawings".

10. Fluid power system schematics shall be drawn in accordance with ASME Y32.10-1967 (R1994) "Graphic Symbols for Fluid Power Diagrams".

11. Dimensions and tolerances shall be indicated in accordance with ANSI 14.5M-1994 (R1999).

12. Surface finishes shall be described in accordance with ANSI 14.5M-1994 (R1999).

**REQ-LS-0473:** This requirement deleted.

### 9.3 Electrical/Electronic Documentation

**REQ-LS-0474:** Except for drawings determined competition sensitive per Section 5(b)(3) of the Statement of Work, the laser system vendor shall provide the following documentation for all electrical and electronic assemblies and modules in the laser system:

1. A top level system block diagram.

2. An interconnection diagram showing all interconnecting cables and connected assemblies and modules in the laser system.

3. An interconnection diagram showing the external connections to the laser system.

4. Pinouts and wire color codes where applicable, for all internal and external connectors and cables except those for COTS items.

5. Schematics, assembly drawings, printed circuit board designs and printed circuit board artwork for all custom printed circuit boards in the laser system.

6. Programmable logic device source code for all programmable logic devices used on custom printed circuit boards in the laser system per section 8(c) of the SOW.

7. Programmable logic device source code for all programmable logic devices used in COTS components where the programmable logic device source code has been modified or customized by the laser system vendor per section 8(c) of the SOW.

### 9.4 Software

For the purposes of this section the laser control system software is defined as all software to implement the laser control system including the code for servo controls including DSP code, PMAC code or other motion control code and the like.

**REQ-LS-0761:** Source code shall be provided for all laser control system software on CD/DVD per section 8(c) of the SOW.

**REQ-LS-0762:** Executables for all laser control system software shall be supplied on CD/DVD.

**REQ-LS-0763:** One copy of any and all software libraries required to build the laser control system software executables shall be supplied on CD/DVD.

**REQ-LS-0764:** A list of any and all code compilers required to build the laser control system software shall be supplied.

**REQ-LS-0766:** All makefiles required for building the laser control system software shall be supplied on CD/DVD.

**REQ-LS-0767:** All configuration files and all data files read by the laser control system software executables at start-up time shall be supplied on CD/DVD.

**REQ-LS-0768:** Any software scripts required to start the laser control system software shall be supplied on CD/DVD.

**REQ-LS-0769:** Any software scripts required to shutdown the laser control system software shall be supplied on CD/DVD.

**REQ-LS-1770:** Any aliases, environment variable definitions, etc. that are required to correctly set up the environment to build or run the laser control system software shall be supplied on CD/DVD.

**REQ-LS-1771:** This requirement deleted.

**REQ-LS-1772:** Full design documentation for the control loops shall be provided in the Manual per section 8(c) of the SOW, to include block-diagrams and control loop tuning procedures.

**REQ-LS-1773:** This requirement deleted (was REQ-LS-0773 which was a duplicate number).

**REQ-LS-1774:** Vendor shall provide documentation for the laser control system software, consisting of:

1. Users Manual: a detailed tutorial describing how to use this version of the software.

2. Functional Descriptions: a description of each routine or module describing its function.

3. Startup/Shutdown procedures: descriptions of the steps necessary to cold start the system and the steps necessary to safely shut down a running system. This document should include descriptions of any configuration files required at start-up time.

4. Installation Manual: a detailed description of the steps necessary to rebuild and install the system from sources.

5. Deleted.

6. Deleted.

7. Any other documentation in addition to the source code describing the software.

# 10 APPENDICES

## 10.1 Appendix A: Spectral characteristics

### 10.1.1 Sodium D2 line

The sodium D2 line wavelength near 589.0nm consists of several hyperfine transitions between ground state $3S_{1/2}$ and excited state $3P_{3/2}$, grouped in two peaks D2a and D2b 1.77GHz apart, where D2a is the highest peak in the profile. Doppler broadening due to the mesosphere temperature of about 200K enlarges every individual transition line by about 1GHz, resulting in the approximately 3GHz-wide profile as shown in Figure 3. The radiative lifetime due to spontaneous emission of a sodium atom in either of the $3P_{3/2}$ excited states is 16 nanoseconds, corresponding to a 10MHz natural line width for each transition.

### 10.1.2 Spectral Bandwidth

The spectral bandwidth shall be tailored so as to maximize photon return from the sodium layer. In most cases this will consist in tuning the laser wavelength to the highest peak of the sodium D2 line, and adjusting the laser spectral bandwidth so as to make the best compromise between high interaction efficiencies near the peak of the sodium D2 line and limited saturation in spreading the laser power over multiple 10MHz-wide velocity group of sodium atoms.

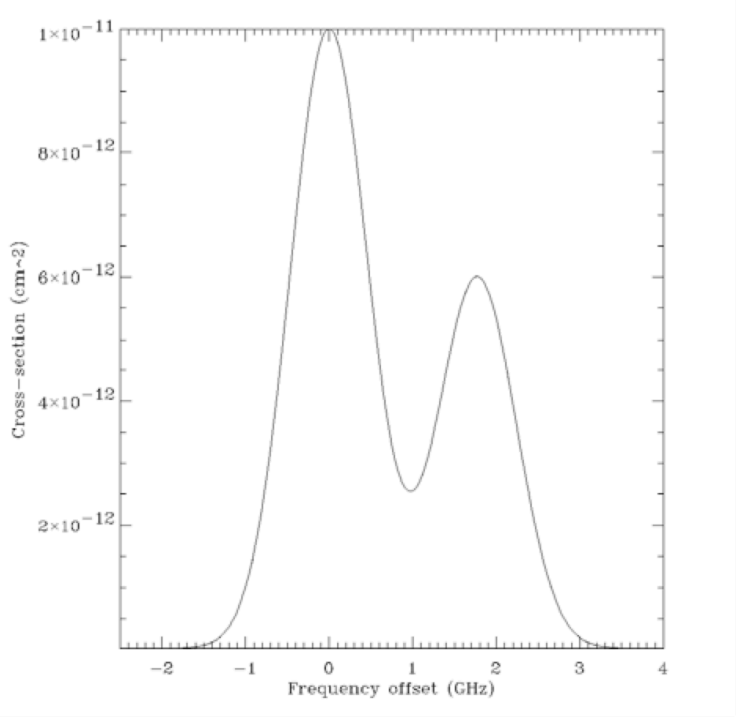


**Figure 3: Cross-section of the sodium D2 line**

The peak cross-section value[3] equals $10^{-11}$ $cm^2$. At T=200K, Doppler broadening is of the order of 1.0 GHz. Together with hyperfine splitting, this gives an overall FWHM = 1.1 GHz for each of the two peaks. The separation between the peak central frequencies is 1.772 GHz.

[3] Peter Milonni *et al*., *Analysis of measured photon returns from sodium beacons*, JOSA A, Vol. 15, No. 1, p. 219 (Jan. 1998)

### 10.1.3 Tunability

MCAO performance will be degraded by the presence of Rayleigh scattered light along the projected laser beams. One solution to this problem is to shift the laser frequency out of the sodium D2 line so that the Laser Guide Star disappears and the Rayleigh background can be calibrated. A frequency shift of **5 GHz** is small enough to ensure that Rayleigh scattered light produced at the detuned wavelength shall have the same intensity as Rayleigh scattered light produced at the sodium wavelength within 0.25%.

## 10.2 Appendix B: Output beam pointing and centering stability

To some extent, it is expected that the output laser beams will exhibit pointing and centering variations in the output plane of the laser system. Low frequency beam pointing and centering variations are expected to result from thermal effects and mechanical flexures, Higher frequency perturbations are expected to result from excitation by vibration sources on the telescope or the specifics of laser system operation. The BTO will include slow and fast pointing and centering control loops to maintain beam pointing on the sky and centering within the projection aperture. The laser beam pointing and centering variations must be small enough to ensure that all laser beams will remain within the Beam Transfer Optics (BTO) acceptance aperture and angle at all times. The aim is to prevent laser beam vignetting by BTO components and fast LGS spot diameter broadening on the sky.

## 10.3 Appendix C: Environment

The environment conditions for which the GS laser system and the Keck I laser system will be subjected to in their lifetime include the following:

- Transportation and shipping from the Vendors facilities to the Gemini South and Keck I facilities
- Transportation to and from the base and mountain facilities
- Storage at the base and mountain facilities
- Assembly/disassembly onto the telescope
- Storage on the telescope
- Operation on the telescope
- Survival

It is recognized that it may be difficult or prohibitively expensive to actually test the laser system under all of these environmental conditions. Where this is the case, these specifications are intended to be used for design and the design shall be verified by analysis or past experience with similar systems.

## 10.4 Appendix D: Potentially Clarifying Definitions and Explanations

### 10.4.1 Laser Guide Star Facility

#### 10.4.1.1 Laser Guide Star Facility

The Gemini South and Keck I Laser Guide Star Facilities (LGSF) are intended provide the GS and Keck I AO systems with a source of coherent light for the optical excitation of the mesospheric sodium layer to enable the production of an artificial beacon source or "guidestar". This laser guide star (LGS) is used to permit improved operation of adaptive optical systems on astronomical telescopes.

Each LGSF has four major subsystems, are the laser system (LS), the beam transfer optics (BTO), the laser launch telescope (LLT), and the safety systems. This requirements document is only for the LS for GS and Keck I. All other LGSF subsystems are outside of the scope of this document.

The Keck I LGSF requires a single laser beam and it is the intention of WMKO to use a fiber to transport the laser light to the LLT, which will be located behind the secondary mirror of the telescope. The LLT will expand the fiber output and project it in the direction the Keck I telescope is pointed.

For the GS LGSF, five laser beams are required in order to create a LGS "constellation" as shown in Figure 4. The five laser beams produced by the LS will be directed to the top end of the telescope by a train of mirrors, which are part of the BTO. The BTO will also adjust laser beam pointing and centering so as to create a 1 arc minute square LGS constellation on the sky with four beams at each corner of the constellation and one beam in the center (see Figure 4). The LLT, located behind the secondary mirror of the telescope, will expand each of the five laser beams. The laser beams will then propagate through the atmosphere until they reach the sodium layer and excite sodium atoms, thus creating the desired LGS constellation.

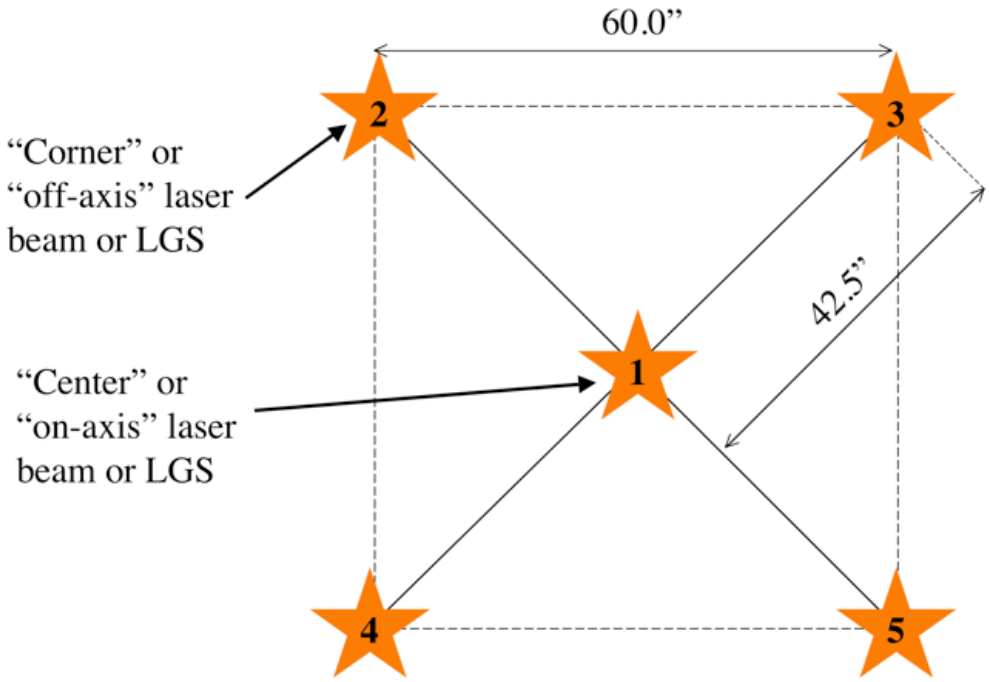


**Figure 4: Laser Guide Star constellation**

#### 10.4.1.2 Beam Transfer Optics

The BTO system, which is not within laser system vendor's scope of work, is another subsystem of the LGS. The BTO subsystem has optical and mechanical interfaces with the laser system. The BTO relays the laser beams to the top-end of the telescope before they are projected onto the sky by the LLT.

#### 10.4.1.3 Laser Launch Telescope

The LLT, which is not within vendor's scope of work, is an optical system that expands the laser beams and projects them onto the sky. The LLT is located behind the secondary mirror of the telescope. The LLT receives the output of the BTO.

#### 10.4.1.4 Safety Systems

The safety systems include all systems that enable safe operation of the LGSF within the observatory and ensure safe laser propagation onto the sky. The safety systems are not within vendor's scope of work. Safety systems include, but are not limited to, outdoor IR and visible surveillance cameras, the laser safety shutters located in the BTO near the output of the LS, and the Gemini Laser Interlock System (LIS) or its equivalent at WMKO.

#### 10.4.1.5 Laser Interlock System

The LIS is a subsystem of the Gemini interlock system (GIS). The LIS is not within vendor's scope of work. The LIS is responsible for generating and handling interlocks enabling safe laser propagation at the observatory. The LIS has electronic interfaces with the laser system.

#### 10.4.1.6 Laser System Engineering

Laser system engineering refers to laser system operations that take place when the laser system is not being used as part of the LGSF.

#### 10.4.1.7 Laser Operation

Laser operation refers to any time when the laser system has been powered up using the start-up procedure or an equivalent manual procedure. Equivalent terms include operation and operation mode. The laser system is in operation any time that it is not shut down or otherwise powered off.

#### 10.4.1.8 Laser propagation

Laser propagation refers to propagation of the laser output beams from the laser system to any of the associated components. During observing laser propagation refers to the laser beam or beams being emitted from the LLT towards the sky.

When the laser beams are propagated, they may be propagated only part way through the related systems as follows:

1. Propagated to the top-end or propagated to the beam dump, meaning that they are relayed to the top-end of the telescope via the BTO to the beam dump mirror (BDM). The BDM is a subsystem of the BTO that prevents propagation of the laser beams from the BTO to the LLT.
2. Propagated to the sky, meaning that the laser beams are emitted from the LLT towards the sky and the dome shutter is open.

#### 10.4.1.9 Laser Shutter

The laser shutter is part of the laser system and is not to be confused with the safety shutter that Gemini and WMKO will implement as part of the safety systems for their LGSF. The safety shutter is not part of the laser system vendor's scope of work. There will be one laser shutter per laser system in order to block all output beams simultaneously.

## 10.5 Appendix E: Applicable documents and drawings

### 10.5.1 GS General Interface Control Documents

For GS all applicable general Interface Control Documents (ICDs) can be downloaded from the Gemini web site at http://www.gemini.edu/documentation/icds.html. Particular attention should be paid to the following ICD documents:

| | |
|---|---|
| ICD-01a | The System Command Interface |
| ICD-01b | The Baseline Attribute/Value Interface |
| ICD-02 | Baseline DHS Interface |
| ICD-03 | Bulk Data Transfer |
| ICD-04 | Logging Information |
| ICD-07b | TCS Subsystem Interface |
| ICD-09 | EPICS Time Bus Driver |
| ICD-10 | EPICS Synchro-Bus Driver |
| ICD-13 | Standard Controller |
| ICD-14 | Core Instrument Control System |
| ICD-15 | DHS Database Interfaces |
| ICD-16 | The Parameter Definition Format |
| ICD-G0015 | Gemini Facility Handling Equipment and Procedure. |

**Index to Requirements**

**Index to Requirements**

**Index to Requirements**

**Index to Requirements**

**Index to Requirements**