GEMINI
8-M Telescopes
Project

MK LGS Laser System Requirements Document

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1. Introduction

1.1. General

This Request for Proposal (RFP) is for the Laser System subsystem of the Gemini Mauna Kea Laser Guide Star (MK LGS) system. Therefore the requirements listed in the present document are for the Laser System only. An overview of the MK LGS system and subsystems is given in section 1.3, along with the definition of other terms specifically related to the Laser System. All acronyms used in the document are listed in section 1.2 as well.

The MK LGS Laser System Requirements Document is divided into six major sections:

(1) Introduction

(2) Performance requirements

(3) Functional requirements

(4) Operational requirements

(5) References

(6) Appendices

1.2. Acronyms

AO	Adaptive Optics
BTO	Beam Transfer Optics
CW	Continuous Wave (laser)
DHS	Data Handling System
FWHM	Full Width at Half Maximum
GIS	Gemini Interlock System
HROS	High Resolution Optical Spectrograph
LGS	Laser Guide Star
LGS CS	Laser Guide Star Control System
LLT	Laser Launch Telescope
MK	Mauna Kea
MK LGS AO	Mauna Kea Laser Guide Star Adaptive Optics
NGS	Natural Guide Star
OCS	Observatory Control System
PSD	Power Spectrum Density
RFP	Request For Proposals
SAD	Status Alarm Database
SALSA	Safe Aircraft Localization and Satellite Acquisition System
TCS	Telescope Control System
WFS	Wavefront Sensor

1.3. Definition of terms and concepts

- **Laser Guide Star Adaptive Optics**

Ground-based telescopes use Adaptive Optics to correct astronomical images from distortion by atmospheric turbulence. Adaptive Optics systems using a Natural Guide Star (NGS) are constrained to limited portions of the sky due to the requirement of a wavefront reference source near the science object. As a result, many targets of interest can not be observed with sufficient resolution or sensitivity. A solution to this problem is the use of an artificial wavefront reference source. When no bright natural guide star can be found close enough to the science target, Adaptive Optics uses an artificial guide star created by shooting a laser at the sky in the direction of the target. This laser excites mesospheric sodium atoms located 90 km above the ground. The sodium atoms re-radiate the light and create an artificial Laser Guide Star (LGS).

- **ALTAIR**

ALTAIR is the name of the Gemini North Adaptive Optics system. This Adaptive Optics system will be able to work both in NGS and LGS modes.

- **Mauna Kea Laser Guide Star System**

The MK LGS system will provide ALTAIR with the LGS source. This system will be part of the Gemini North facility and consists of four identified subsystems. These subsystems are the Laser System (LS), the Beam Transfer Optics (BTO), the Laser Launch Telescope (LLT) and the Safe Aircraft Localization and Satellite Acquisition System (SALSA). These subsystems will be controlled by the Laser Guide Star Control System (see appendix (f)). This Request for Proposal is only for the Laser System; all other subsystems mentioned in this document will be obtained separately by Gemini. The laser beam produced by the Laser System will be directed to the top end of the telescope by a train of mirrors which are part of the Beam Transfer Optics. Then the laser beam will be expanded by the Laser Launch Telescope, located behind the secondary mirror of the telescope. The laser beam will propagate into the atmosphere until it reaches the sodium layer and excites the sodium atoms, thus producing the Laser Guide Star.

- **MK LGS Laser System Requirements Document**

The MK LGS Laser System Requirements Document is the present document. This document presents the requirements for the MK LGS Laser System only. It does not present any requirements for any other subsystems of the MK LGS system since this Request For Proposal is only for the Laser System.

- **Strehl ratio**

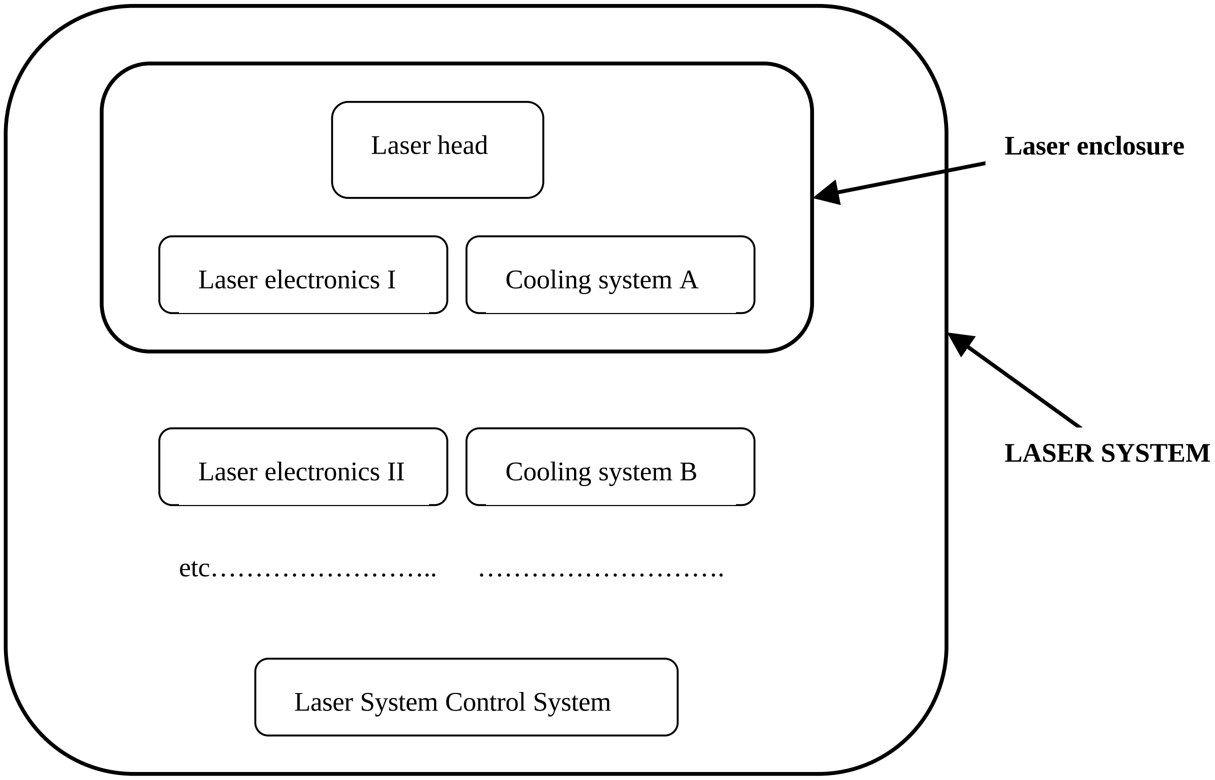
The Strehl Ratio of an image obtained at the focal plane of a telescope gives a measurement of the image quality, including all static (telescope, instrument) and dynamic (turbulence, telescope vibrations) aberrations. The Strehl Ratio is defined as the ratio of the peak intensity of the aberrated profile of a point source (a natural star) to the peak of the fully diffraction-limited profile of the same point source. The higher the Strehl Ratio (the closer to one), the better the image quality.

- **Photon return**

The artificial star is created by the fluorescence of sodium atoms which have been excited by the laser light. The fluorescence photons are collected by the primary mirror of the telescope after they have traveled back to the earth through the atmosphere. We call photon return the number of photons received at the primary mirror of the telescope per unit of surface and per unit of time. The photon return number is expressed in photons/cm^2/second.

- **Laser System**

The Laser System is a subsystem of the Laser Guide Star system. This document presents the specifications and technical requirements for the Laser System only. The Laser System is the subject of this Request For Proposal. The Laser System provided by Vendor must include all components, both hardware and software, necessary to meet the performance and other requirements given in this document. These components must include, but are not limited to, the laser head, the laser enclosure, the laser electronics, a control system, cooling systems, and any diagnostic system that is needed to maintain the production of the sodium light.



- **Laser head**

The laser cavity and other laser optics or diagnostics surrounding the cavity are specifically called the *laser head* of the laser system. The laser head is housed by the *laser enclosure*.

- **Laser enclosure**

The laser enclosure is the thermal enclosure which houses the laser head, plus part or totality of the laser electronics and part or totality of the laser cooling systems. The laser enclosure is part of the Laser System.

- **Laser electronics**

The laser electronics are all the electronics needed to make the Laser System work. They may be housed in the laser enclosure, or located somewhere else on the telescope or in the dome. There may be electronics both in the laser enclosure and somewhere else in the dome.

- **Laser System Control System**

The Laser System Control System is the hardware and software which control the Laser System. It is not to be confused with the LGS Control System described in the following. The Laser System Control System is part of the Laser System.

- **Control room**

This is the room from where observations are made during the night. This room is located on the first floor of the Mauna Kea telescope. Virtually anything in the observatory can be controlled from the control room. The Laser System shall be controlled from the control room as well.

- **Beam Transfer Optics**

The Beam Transfer Optics (BTO), which are not within the scope of work for this RFP, are another subsystem of the Laser Guide Star system. The BTO subsystem has a mechanical interface with the Laser System (see definition of the *Laser System output aperture* in the following). The Beam Transfer Optics relay the laser beam to the top-end of the telescope before it is launched to the sky by the Laser Launch Telescope.

- **Laser Launch Telescope**

The Laser Launch Telescope (LLT), which is not within the scope of work for this RFP, is the telescope that expands the laser beam and focuses it on the sodium layer. It has no interface with the Laser System.

- **LGS Control System**

The Laser Guide Star Control System is not within the scope of work for this RFP. It is responsible for the interface between the Telescope Control System (TCS) and the four Laser Guide Star subsystems: the Laser System (LS), the Beam Transfer Optics (BTO), the Laser Launch Telescope (LLT) and the Safe Aircraft Localization and Satellite Acquisition System (SALSA).

- **Laser System start-up**

The Laser System start up is the period of time when the Laser System is turned on and powered up to its full power level.

- **Laser System shutdown**

There are two levels of shutdown.

  - **End of operation shutdown**

This procedure shutdowns the Laser System at the end of operation. The laser light is extinguished and most electronics are turned off sequentially. This is a normal shutdown.

  - **Emergency shutdown**

This procedure suddenly turns off the electrical power for all the Laser System electronics. This is an emergency shutdown.

- **Laser System set-up**

We call “set-up”, set-up time or set-up mode any time when the Laser System is not used as part of the MK LGS system. Set-up time is engineering time for the Laser System alone.

- **Laser System operation**

We call “operation”, operation time or operation mode any time when the Laser System is used as part of the MK LGS system.

- **LGS AO observation**

We call “observation”, observation time or observation mode any time when the LGS AO system is used for science observation.

- **Laser System output & Laser System output aperture**

The output of the Laser System is a laser beam that meets all the performance requirements described in section 2. The location of the Laser System output is represented by an aperture, which also defines a physical interface between the Laser System and the Beam Transfer Optics. This aperture is called the *output aperture* of the Laser System. All the laser light requirements must be met at the output of the Laser System, in the plane of the output aperture.

- **Output power**

The output power is the Laser System average power at the sodium wavelength out of the output aperture.

- **“Requirement” & “goal”**

All specifications and requirements given in this document must be met by the Laser System provided by Vendor. Items specifically identified as goals do not have to be met by the Laser System, although it is highly desirable that it does.

1.4. The MK LGS Laser System

1.4.1. Interfaces

The Laser System has interfaces with:

- the Beam Transfer Optics (see definition of *Laser System output aperture* above, sections 2.3.5.5 and 4.3.3.3)
- the LGS Control System (see sections 3.5.3.2.2 for interface requirements, 3.5.3.3 for interface goals and appendix (f) for additional information on the LGS CS)

See the following section for interfaces with:

- Mechanics (3.1)
- Electronics (3.2)
- Cooling systems (3.4)
- Software and related hardware (3.5)
- Safety systems (3.6)
- Interlock system (3.7)

1.4.2. Laser System location

Several possible locations are envisioned for the Laser System at the Mauna Kea telescope site. Drawings of the telescope as well as drawings of the different possible laser locations are given in appendices. All telescope-specific terms are described in the *Telescope Overview (f/16 top-end)* drawing.

All parts of the Laser System will either be mounted at the same location, or they will be split between several locations. For instance, part or all of the electronics could be at a different location than the laser head of the Laser System.

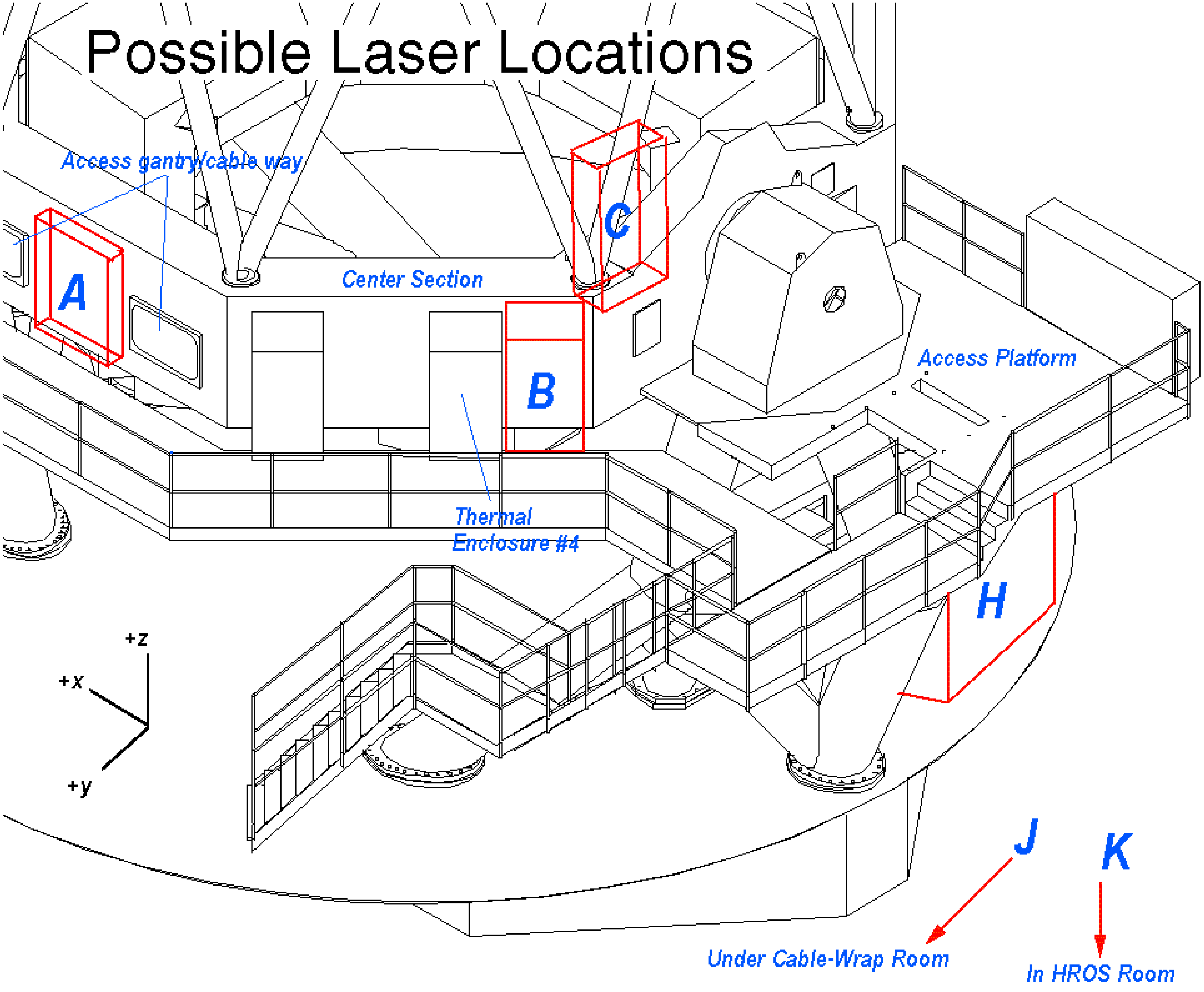
The goal is to mount the laser head as close as possible to the LLT, so that the beam path between the laser head and the LLT is kept as short and simple as possible. The laser head location is an issue because originating the beam off the center section requires the use of more fold mirrors with associated complexity, loss and efficiency and degradation of the beam quality.

For this reason, it is highly desirable that the laser head of the Laser System is mounted on the telescope itself either at location A or location B. Those locations as well as other possible locations for parts or the entire Laser System are indicated on the drawings below. A general description of all locations and miscellaneous remarks follow. Space and mass constraints are given in section 1.4.2.1.2 and related drawings are given in appendices. Further information will be made available upon request.

1.4.2.1.1. Description of possible locations for parts or all the Laser System

- A: on telescope center section, (X=0,+Y) location in between both access gantry/cable ways
- B & B’: on telescope center section, (-X, +Y) location next to thermal enclosure # 4
- C: on telescope truss (-X, +Y)
- H: on rotating floor section, under -X access platform
- J: in the room under cable wrap room, in the pier
- K: in the High Resolution Optical Spectrograph (HROS) room
- thermal enclosure # 4

Possible Laser Locations



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AutoCAD LT PSOUT
Preview:
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with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers.

1.4.2.1.1.1. Location A

The Laser System could be located on the mirror support cell on the X=0, +Y wall in between both access gantry/cable ways. This location could be preferred to location B since a laser mounted here would only suffer from changing gravity along one axis. Space is limited here as the access gantry/cable ways must remain open. The space in between the holes is also crowded with boxes and balance weights but it is possible to relocate those elements elsewhere. Note that a platform hangs over location A by about 0.25 m in depth, which gives a hard limit if we consider loosening height constraints for this location. It also implies that we will not be able to steer the output beam of the laser through the platform i.e. the first mirror of the BTO will have to be positioned far enough from the center section wall to allow a clear shot to the telescope top-end.

Issues with this location: changing gravity, space constraints, heat dissipation

1.4.2.1.1.2. Locations B and B'

The laser system could be located on the telescope center section on the -X, +Y wall next to the thermal enclosure # 4 containing the mirror heating system electronics. We give two different space envelopes for this location (B and B') depending on whether location C is used at the same time (B') or not (B).

Issues with this location: changing gravity, space constraints, heat dissipation

1.4.2.1.1.3. Location C

Some electronics of the Laser System could be mounted on the telescope truss (-X, +Y), close to location B'. The exact location is somewhat free although the heat dissipation would have a higher impact on the turbulence above the primary mirror.

Issues with this location: heat dissipation, mounting and access

1.4.2.1.1.4. Location H

Below the -X access platform next to the mount there is a large enough space which could be used to house a small laser enclosure. This would allow a workspace with constant gravity vector as well as keep the laser relatively close to the telescope. Note that this location rotates with the telescope when it moves in azimuth.

Issues with this location: heat dissipation, difficult optical path to the telescope for the BTO

1.4.2.1.1.5. Location J

The Laser System could be located in the room just below the cable wrap area inside the pier. The beam path would be through the center column inside the pier, up to the crawl space just beneath the mount base on the observing level, over to just below the -X access platform, then up onto the platform and into the elevation axis.

Issues with this location:

- transport of the Laser System: access to this area is very restricted (around cable wrap, through a hatch way and down a ladder) with no lifting equipment. This means *that the system would have to be assembled in parts.* Individual parts must weigh less than 100 kg and be 2 m x0.5 m x.0.5 m max.
- very long BTO

1.4.2.1.1.6. Location K

The laser system could also be located in the room dedicated to the High Resolution Optical Spectrograph at the bottom of the pier. Location K provides enough room for a standard 8' x 4' optical table. The beam path would be through the center column inside the pier, up to the crawl space just beneath the mount base on the observing level, over to just below the -X access platform, then up onto the platform and into the elevation axis.

Issues with this location:

- very long BTO
- more constrained requirements in terms of heat and vibrations created by the Laser System due to the future implementation of the High Resolution Optical Spectrograph in this room.

1.4.2.1.1.7. Thermal enclosure # 4

This thermal enclosure is only about half full and might be used as a location for some laser electronics. About 12 U of 19” rack space, 500 mm deep is available.

1.4.2.1.1.8. Alternative locations for the Laser System electronics on the telescope

The Laser System electronics, part or all of it, could be located at other possible locations on the telescope, depending on whether they have to be close to the laser head or can be mounted remotely. These alternative locations could be:

- in bigger thermal enclosures than the ones that are already mounted on the telescope, providing that the heat dissipation requirement is met and there is no difficulties like access problems or limited space envelopes
- hanging in place on the (modified) access platform railing
- others

1.4.2.1.2. Space and mass constraints

Location	Available space			Maximum weight (kg)
	Length	Thickness	Height	
A	0.8 m	0.6 m	2.0 m	< 300 kg
B	0.8 m	0.6 m	2.8 m	< 300 kg
B’	0.8 m	0.6 m	1.4 m	< 300 kg
C	0.8 m	0.6 m	1.5 m	< 300 kg
H	1.5 m	1.0 m	2.0 m	< 2000 kg
J (total) (parts)	4.0 m < 2 m	2.3 m < 0.5 m	2.0 m < 0.5 m	< 2000 kg < 100 kg
K	4.0 m	2.3 m	2.0 m	< 2000 kg
Th. Encl. #4	0.45 m	0.45 m	0.74 m	-

The space envelopes for each location are illustrated with AutoCAD drawings (see appendices).

Some extensions of the space and mass envelopes may be subject to further negotiations if necessary for the Laser System proposed. Proposals must include a plan showing where each element of the proposed Laser System would be placed among the possible locations.

2. Laser System performance requirements

The Laser System performance requirements are driven by the overall MK LGS AO performance requirements in terms of Strehl ratio at the focal plane of the science instrument.

2.1. MK LGS AO system performance requirements

The science driver for the Laser System in the MK LGS AO system is to produce the brightest possible sodium laser star, with the smallest possible angular spot diameter, to achieve a Strehl ratio as high as possible on an image which has been corrected by the MK LGS AO system. The top-level MK LGS AO science requirement to meet is a **Strehl Ratio > 0.2 @ 1.6 μm at 45 degrees zenith angle**. We have used the Strehl ratio requirement to derive all the performance requirements for the Laser System. Those requirements are presented in the following sections.

2.2. Photon return requirement & goal

We simulated the ALTAIR response to a LGS type source and used the results of the simulation to derive the photon return requirement to meet the science requirement stated above. Note that the beam quality of the laser system and the many additional wavefront aberrations added to the beam before it is launched to the sky are accounted for in the photon return requirement. This requirement also accounts for some margins.

The top-level science requirement in terms of photon return at the primary mirror of the MK telescope is **160 photons/cm^2/second.** The goal is **240 photons/cm^2/second.**

2.3. Laser light requirements

2.3.1. Output power

It is not possible to fix the same power requirement for all possible laser systems. This requirement has to do with the physics of the interaction between the laser light and the sodium atoms. This document does not review how various lasers interact with sodium atoms depending on their temporal and spectral format, but references [1-5] do so. Reference [5] is given in appendix (e). The sodium D2 line profile is given in appendix (d).

2.3.1.1. Output power requirement calculation

The laser output power requirement must be derived from the photon return requirement at the primary mirror of the MK telescope. **Vendors are required to calculate the power requirement which corresponds to the type of Laser System they propose.** Reference [5] gives some examples of this calculation when using an ideal laser beam with no wavefront aberration in the LLT pupil (see appendix (e)). Following this reference, sections 2.3.1.2 and 2.3.1.3 give the power requirement for three different types of lasers.

The following assumptions will be used to calculate the laser system output power which matches the photon return requirement:

- 45 degrees zenith angle
- Median to poor seeing conditions at Mauna Kea: r_0=17,2 cm @ λ=589 nm (equivalent to 0.7 arcsec seeing @ 0.55 μm)
- Average to low sodium column density at zenith: $C_S=2*10^9$ atoms/cm^2
- Sodium layer altitude at zenith = 90 km

- Sodium layer thickness at zenith = 10 km
- Atmospheric transmission coefficient at zenith = 0.8 (one way)
- BTO transmission coefficient = 0.8 for a Laser System located on the telescope, 0.6 for a Laser System located further away (e.g. in the pier of the telescope)
- LLT transmission coefficient = 0.9
- LLT pupil diameter = 45 cm
- Laser beam intensity diameter @ $1/e^2$ on LLT = 25 to 45 cm (nominal is 30 cm)
- MK telescope entrance pupil diameter = 7.9 m.

2.3.1.2. Power requirement & goal for a CW laser

To serve as a reference for the calculation of the power requirement for any type of laser, we convert the photon return requirement into a power requirement for a hypothetical continuous wave laser. This laser has the following characteristics:

- the laser is *continuous wave*
- the laser is *longitudinally monomode*
- the full width at half maximum (FWHM) of the laser mode is *10 MHz* (equal to the homogeneous width of sodium atoms)
- the laser mode is *centered on the peak of the D2 line F=2 → F=3 hyperfine transition*
- the laser is *circularly polarized*

Then the equivalent power requirement at the output of this CW laser (prior to any propagation through the beam transfer optics or the atmosphere) is **12.2 W**. The goal is **18.3 W**.

2.3.1.3. Power requirement & goal for other types of lasers

The conversion of the power requirement for this particular type of CW laser into a power requirement for other types of lasers is not straightforward as it depends on the temporal and spectral format of those lasers. Vendors are welcome to use the following as a guideline to calculate the power requirement for the laser they propose. Note that *Vendors who would propose a Laser System identical or very similar to one of those three lasers given as examples are not required to calculate the power requirement again.*

2.3.1.3.1. Examples

We will consider two non CW laser formats as examples. We call the CW format described in section 2.3.1.2 the *CW laser*, and define two other formats: the *Long pulse laser* and the *Macro-micro pulse laser.* Pulse lengths are said to be *long*, *macro* or *micro* with respect to the sodium excited state lifetime (16 ns).

To some extent it is possible to scale the power requirement calculated for the CW laser to other laser formats [4-5]. To do so, we use the 'slope efficiency' numbers (SE) given in references [4-5]. **The laser output power requirement is inversely proportional to SE**. For the CW laser, SE = 0.26 photon.m^2/ms/W/atom. Note that *the slope efficiency numbers assume that there is no saturation at the sodium layer.*

In case saturation would be reached, the following power requirements are no longer valid. Therefore the output power requirements given as examples would increase. Section 2.3.1.3.2 gives some information on how to take saturation into account in the laser output power requirement calculation.

The laser location also has an influence on the scaling coefficient because it changes the BTO transmission coefficient, since more relay mirrors are actually needed to bring the beam to the top-end if the laser system is located far from it. We suppose that the CW laser would have to be located at location J or K whereas the Long pulse laser and the Macro-micro pulse laser would possibly be located at location A or B (see section 1.4.2 for these locations on the telescope). For the CW laser, located about 50 m far away from the

LLT, $T_{BTO} = 0.6$, whereas for the two formats below, assuming that the laser heads are mounted on the telescope about 20 m away form the LLT, we use $T_{BTO} = 0.8$. **The laser output power requirement is inversely proportional to T_{BTO}.**

	Long pulse laser	***Macro-micro pulse laser***
Temporal format	100 ns pulse @ 30 kHz rep. rate	150 µs @ 800 Hz rep. rate 700 ps @ 100 MHz rep. rate
Spectral format	Phase modulated Multimode FWHM=3 GHz	Mode-locked Multimode FWHM=1 GHz
Polarization	Linear or circular	Circular
SE (photon.m^2/ms/W/atom)	0.1	0.33
T_{BTO}	0.8	0.8
Scaling coefficient compared to the *CW laser:* $\frac{SE_{CW} \times T_{BTO,CW}}{SE_{laser} \times T_{BTO,laser}}$	$\frac{0.26\times0.6}{0.1\times0.8}=1.95$	$\frac{0.26\times0.6}{0.33\times0.8}=0.59$
Calculated power (W)	$12.2\times1.95 = 23.8$	$12.2\times0.59 = 7.2$
Power requirement (W)	**21**	**7**
Calculated power goal (W)	$18.3\times1.95 = 35.7$	$18.3\times0.59 = 10.8$
Power goal (W)	**30**	**10**

2.3.1.3.2. Saturation issue

2.3.1.3.2.1. CW laser

The power requirement and goal given above do not take into account saturation of the sodium atoms. A monomode CW laser that meets the power requirement (12.2 W) and at the same time the beam quality requirement (see section 2.3.5.3) will *actually reach* saturation. A monomode CW laser that meets the power goal (18.3 W) and the beam quality requirement as well will of course saturates the sodium atoms even more heavily. If nothing is done, then saturation will lower the expected photon return and the photon return requirement (resp. goal) will not be met.

At such power levels out of a CW laser, the way to beat the saturation effect is either to enlarge the mode linewidth or to go longitudinally multimode. Assuming that those longitudinal modes are not too far away from the peak of the sodium D2 line (say by no more than 100 MHz), then saturation would decrease in proportion with the number of longitudinal modes. Vendors who would propose a CW laser for the MK LGS Laser System would have to take these considerations into account in order to design their system.

2.3.1.3.2.2. Other types of lasers

The scaling coefficients given in section 2.3.1.3.1 are only valid for non-saturated sodium atoms. Consequently, if relevant, saturation should be included when calculating the laser power requirement for laser systems similar to the Long pulse laser, the Macro-micro pulse laser or any other laser.

The laser spot size at the sodium layer is of prime importance in that calculation since it defines the light flux and the saturation parameter for the excited atoms. Laser systems with high beam quality will produce smaller spot sizes. Therefore these laser beams are more likely to saturate sodium atoms. Here are some values for the saturation intensities which can be found in the references [1-5]:

- *Monomode CW laser*: $I_{sat} = 6.4$ mW/cm^2 (10 MHz linewidth)
- *Multimode CW laser*: $I_{sat} =$ Nmodes * 6.4 mW/cm^2 (10 MHz linewidth for each mode)
- *Long pulse laser*: $I_{sat} = 5$ W/cm^2 (FWHM = 3 GHz)
- *Macro-micro pulse laser*: such a format does not saturate for the range of laser powers and spot sizes considered here.

2.3.1.3.3. Rules of thumb

For laser formats which are close to the examples presented above, it is possible to assess roughly the SE numbers by looking at the following parameters.

- Duty cycle, energy per pulse and pulse length: these parameters are related to saturation and optical pumping.
- Spectral width (FWHM), frequency center of the laser spectrum and longitudinal mode spacing: these parameters are related to the cross-section value of the absorption and the number of sodium atoms velocity groups which are excited.

2.3.2. Wavelength

The wavelength of the laser beam is about **589 nm**. It will be precisely locked (i.e. actively stabilized) on the sodium D2 line. The central wavelength of the laser will be chosen so as to maximize the photon return from the sodium layer, depending on the temporal and spectral format of the laser.

2.3.2.1. Examples

2.3.2.1.1. CW laser

The central wavelength should be actively locked on the peak of the D2 line F=2 → F=3 hyperfine transition, which will give the highest photon return. It should be stable by no more than the homogeneous width of the sodium excited state, that is 10 MHz.

2.3.2.1.2. Long pulse laser

The central wavelength should be chosen in such a way that the laser spectrum overlaps the sodium D2 line (see section 2.3.3).

2.3.2.1.3. Macro-micro pulse laser

The central wavelength should be locked on the peak of the D2 line F=2 → F=3 hyperfine transition.

Note that vendors are welcome to propose schemes that would enable re-optical pumping of atoms which might be "lost" in other substates than those involved the F=2 → F=3 hyperfine transition. It could be desirable that the central wavelength were not exactly set on the peak but close to it, in between the two main hyperfine components of the sodium line (see appendix (d): Sodium D2 line). If possible, it should be shifted by, say, 100 or 200 MHz towards the second peak. Calculations showing how such a shift could improve photon return should be done prior to the choice of the central wavelength.

2.3.2.2. Other lasers

For any laser other than the three examples presented above, some calculations are required so as to prove that the optimum choice has been made for the central wavelength.

2.3.3. Temporal and spectral formats

The laser can be either continuous wave or pulsed, provided the photon return requirement is met. The laser temporal and spectral formats (e.g. pulse length, mode linewidth, number of longitudinal modes, etc.) should be consistent with the optimization of the laser efficiency and it should aim at minimizing saturation.

2.3.3.1. Pulsed lasers special requirement & goal

The Gemini North Adaptive Optics system ALTAIR has a required sampling frequency of 1 kHz. In case the laser is pulsed, pulse repetition rates between 600 Hz and 1 kHz or above 5 kHz are acceptable. Pulse repetition rates between 600 Hz and 1 kHz will be preferred , with a **goal of 1 kHz**. This will make it possible to get rid of Rayleigh scattering by means of time-gating. Pulse repetition rates below 600 Hz and between 1 kHz to 5 kHz are unacceptable.

2.3.3.2. Laser tunability

Note that in some cases, the laser frequency will have to be tunable. See the Laser System Operation Requirements, section 4.1.4.3.

2.3.4. Polarization

The laser polarization must be **linear**. If the photon return can be enhanced by circular polarization for a given laser format, and if the output power requirement calculation takes this enhancement into account, it will be Gemini's responsibility to change the laser beam polarization from linear to circular before the laser beam is launched to the sky.

2.3.5. Spatial mode

2.3.5.1. Output beam diameter

We note w_0 the waist (i.e. $1/e^2$ intensity radius) at the output of the laser, so that 2 w_0 is the beam diameter at the output of the laser. The beam diameter at the output of the laser system will be **2 w_0 = 3.5 mm**.

2.3.5.2. Beam divergence

The beam divergence of the laser shall be as low as possible, i.e. the laser beam shall be collimated. The beam divergence shall be **no more than 0.21 mrad** (full angle).

2.3.5.3. Beam quality: 60 % encircled energy criteria

The beam quality requirement is expressed in terms of encircled energy. The idea is to produce the smallest spot as possible at the sodium layer. The spot size will be enlarged by the non-diffraction-limited nature of the laser beam plus other phenomenons (e.g. atmospheric turbulence, spot elongation on some subapertures of the LGS AO system).

The far-field angular diameter of an ideal 30 cm beam at the Laser Launch Telescope is:

$2\ \theta_0 = 2\ \lambda\ /\ (\ \pi\ w_0\ ) = 0.52$ arcsec where w0 = $1/e^2$ intensity radius = 15 cm.

For such an ideal gaussian beam, the energy encircled by a cone of diameter $2\ \theta_0$ is: $EE\ (\theta = \theta_0) = 86\ \%$.

For the $1/e^2$ angular radius measured in the far field by the vendors, the beam quality requirement is:

EE ($q = q_{\mathbf{0\ measured}}$**) > 60 %** where $\theta_{0\ \mathrm{measured}}$ is the $1/e^2$ intensity angular radius measured by the vendor.

This requirement is more or less equivalent to a beam which is 1.5 times diffraction-limited.

Vendors are welcome to use any additional measurement of the beam quality, e.g. power in the bucket, M^2 value, wavefront aberrations, etc., providing that it is demonstrated that the 60 % encircled energy requirement is met. The measurement method will be carefully described and all relevant parameters of the experiment will be listed. The way to derive the 60 % encircled energy measurement from any other beam quality measurement will be discussed.

2.3.5.4. Spatial filter

Note that a spatial filter may be used to help to meet the beam quality criteria. However the spatial filter must not be used at the expense of the output power and beam stability requirements.

2.3.5.5. Laser System output aperture

The aperture which represents the output of the Laser System and the interface with the Beam Transfer Optics will be large enough so that it does not degrade the laser beam characteristics in terms of power and beam quality.

2.3.5.5.1. Power loss

The aperture will not produce more than 0.1% of laser power loss on the laser beam.

2.3.5.5.2. Far-field intensity reduction

The aperture will not lead to a far-field intensity reduction of the central lobe greater than 1 %.

2.3.5.5.3. Aperture diameter

In order to meet the two requirements above, the aperture diameter will be **10 mm ± 0.1 mm**.

2.4. Laser System Performance stability

The following parameters must keep stable over a whole observation night (12 hours). In the following, the notation Δx stands for a peak to peak variation of the parameter x.

2.4.1. Output power

P = laser output power

$\Delta P < 5$ %

2.4.2. Wavelength

ν_0 = laser central frequency

$\Delta\nu_0 < 10$ MHz

2.4.3. Spatial mode

2.4.3.1. Output beam diameter

2 w_0 = output beam $1/e^2$ diameter

$\Delta\,(2w_0) < 100\ \mu$m

2.4.3.2. Beam location

The laser beam location will be actively controlled so that it will be fixed in the output plane of the Laser System. The laser beam will be centered relatively to the center of the output aperture. The centering will be better than 1 % of the output aperture diameter (for a 10 mm diameter, this is 100 µm).

2.4.3.3. Beam divergence

The full divergence angle of the laser beam will not vary by more than 10 % peak to peak of its nominal value. For a full divergence angle of 0.21 mrad, this is 21 µrad.

2.4.3.4. Beam quality

EE = encircled energy

$\Delta EE < 5$ %

2.4.3.5. Beam pointing stability

2.4.3.5.1. Beam pointing stability over time

The requirements on the beam pointing stability are driven by the LGS spot size at the sky. The LGS spot must not move on the sky by more than 0.1 arcsec = 0.48 µrad over 1 ms. This corresponds to about 1/4 of the laser spot diameter along the x and y axis without taking atmospheric turbulence into account. The requirement is loosened for a longer period of time because the BTO will have beam pointing servo-controls to correct for the telescope flexures. Over 1 s, the LGS spot must not move by more than 8 µrad on the sky.

The magnification coefficient between the output beam diameter and the laser beam diameter on the LLT primary mirror might vary between 70 to 130. Therefore the requirements are set for the smallest magnification coefficient (70):

$\alpha_{laser} < 34\ \mu$rad over $\Delta t = 1$ ms

$\alpha_{laser} < 0.6$ mrad over $\Delta t = 1$ s

where α_{laser} = Laser System angular jitter (peak to peak)

2.4.3.5.2. Beam pointing stability over temperature

T = Laser Enclosure temperature

$\alpha_{laser} < 0.6$ mrad over $\Delta T = 1$ Celsius degree

2.4.4. Polarization

The beam polarization will be stable to better than 1 %.

3. Laser System functional requirements

3.1. Mechanics

3.1.1. Handling, mounting, removal and transport

The Laser System modules will be mounted using standard metric fasteners and tools. Interface components will be designed to provide good repeatability on dismounting and re-assembling parts.

Handling features will be provided on all components unless they are inherently easy to handle without risk of damage. Handles (fixed for preference) for components up to 25 kg, heavier components and sub assemblies will be provided with lifting eyes or ‘A’ brackets.

Components mounted on the center section of the telescope will be mounted with the telescope pointing at Zenith. In this position, the dome crane will be used to handle large sub assemblies and personnel will have access to the area by means of the center section walkway.

Assembly instructions must be clear, with parts lists and a check list.

3.1.2. Environment requirements

Two separate environmental conditions are specified. The first is involved with general site operations and the second with operating while mounted on the telescope. It is recognized that it may be difficult or prohibitively expensive to actually test the Laser System under all of these conditions. Where this is the case, these specifications can be used as a guide for the design and verified by analysis or experience with previous systems. This document is little more than a description of the conditions experienced by existing instruments in transit or operating at Mauna Kea.

3.1.2.1. Telescope Operation Handling Environment

The telescope operations environment is those conditions experienced under normal telescope operations including:

- Storage at the base and mountain facilities
- Assembly/disassembly onto the telescope
- Storage and operation on the telescope.

After repeated cycles of the above conditions the Laser System must meet its operating performance requirements with no intervention from the operations staff other than routine tasks (handling, connecting services, etc.).

Table 1: Telescope Operation Handling Environment	
Condition	**Requirement**
Altitude	sea level to 4300m
Ambient air temp	-15°C to +25°C
Ambient air temp step	±25°C
Ambient light	Night time observing conditions to normal laboratory lighting conditions
Relative humidity[2]	0% to 95%: system operating (may be not to spec. above 90%) 95% to 100% with condensation: survival
Wind speed	0 to 33 m/sec external wind
Gravity orientation	Depends on the Laser System location[4]
Vibration (minimum integrity)[1, 3]	Depends on the Laser System location[4] PSD 0.0008 g^2/Hz, 20-1000 Hz in all axes: this can be taken as a starting point.
Shock[3]	Depends on the Laser System location[4] A peak acceleration of 2.0g can be taken as a starting point.
Seismic base acceleration[3]	0.4g, 0.5 Hz to 100Hz, any axis
Seismic acceleration at center section[3]	2.0g, 0.5 Hz to 100Hz, any axis
Mechanical Interface	handling cart or facility cranes
Cleanliness	Occasional wind blown dust, sand & insects

[1] IAW MIL-STD-810E, July `89 section 514.4-39

[2] Frequent low humidity levels increase the risk of electrostatic discharge damage to sensitive electronic devices.

[3] It shall be demonstrated by analysis that the Laser System meets those requirements (no vibration testing experiment required).

[4] See section 1.4.2.

3.1.2.2. Operating Environment

The operating environment is those conditions experienced under normal telescope operations if the Laser System is mounted on the telescope and in use. The Laser System performance requirements must be met under these conditions.

Table 2: Operating environment	
Condition	**Requirement**
Altitude	sea level to 4300m
Ambient air temp	-5°C to +20°C

Median air temp	0°C
Ambient air temp rate of change during the night	±0.2°C/hour
Relative humidity[1]	0% to 90%
Wind speed	0 to 5 m/sec
Gravity component limits[2]	Y axis 0g to -1g Z axis -1g to 0g
Vibration[3]	Depends on the Laser System location[4] PSD $1x10^{-5}$ g^2/Hz, 20-1000Hz, 6db/oct drop- off to 2000Hz: this can be taken as a starting point.
Cleanliness	Occasional wind blown dust, sand & insects

[1] Frequent low humidity levels increase the risk of electrostatic discharge damage to sensitive electronic devices.

[2] The coordinate system is the one provided on the drawing describing the possible laser locations in section 1.4.2.

[3] It shall be demonstrated by analysis that the Laser System meets those requirements (no vibration testing experiment required).

[4] See section 1.4.2.

3.1.3. Factors of safety for structural component design

A minimum safety factor of 4 on Yield strength will be used for all structural elements.

3.1.4. Drawing standards

All drawings and geometric tolerancing must comply with ANSI Y14.1 M standards. Preferred software CAD package is AutoCAD 14.

3.1.5. Component finish and protection from corrosion

Non critical surfaces will have a minimum surface finish quality of 3 microns or better unless function dictates otherwise.

All components will be finished by removing sharp edges (unless the function of the part requires this) and burrs. All mild steel components will be cleaned, de-greased, primed and painted with a high performance paint such as epoxy, or polyurethane. Aluminum component will be anodized unless function dictates painting (for example for anti-reflection or to lower emissivity).

Mild steel surfaces that cannot be painted for functional reasons (accurate interface surfaces) will be protected by a non-tracking anti-corrosion dry film lubricant.

3.1.6. Elevated Ozone levels

At the Mauna Kea site, elastomeric components and flexible tubing must be selected from materials that are resistant to elevated ozone levels.

3.2. Electronics

3.2.1. Gemini standards

3.2.1.1. Standardization

The following standards shall be applied to ensure compatibility with existing telescope systems.

3.2.1.1.1. Connectors

Where possible (for example, when connecting power and data signals between units) an appropriate ITT-Cannon MIL-C-26482 Series 1 KPT or KPSE connector shall be employed. Use of keyed connectors to lower the risk of accidental connector-swapping is strongly encouraged.

3.2.1.1.2. Cable and signal identification

All external cables shall be uniquely identified and labeled. The labeling and identification shall strictly adhere to the appropriate Gemini standard (see Gemini Electronic Design Specification SPE-ASA-G0008) and 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 not a substitute for clear labeling.

3.2.1.1.3. Electronic system documentation

All electronic circuit schematics and printed-circuit board (PCB) designs must be supplied in both printed and electronic form. The electronic form shall be in either AutoCAD 14 or OrCAD V9.0 native format or 100% compatible with it. An alternative if this is not possible is to submit the documents in DXF format.

3.2.1.1.4. Environmental rating

All electrical and electronic components shall be rated for operation below zero degree Celsius (rating to minus twenty degrees Celsius is sufficient). The ambient temperature in the telescope dome frequently falls below zero degree Celsius for extended periods. The vendor will ensure that electronic equipment supplied by third parties – for example, as part of a sensor package – meets this requirement.

3.2.1.1.5. Electrical components

All commercially available electrical components have to be UL listed. Items which do not meet this requirement will have to be approved by Gemini prior of being incorporated into the system.

3.2.1.2. Signal Transmission

To minimize the risk of spurious operation of the LGS and other systems, adherence to the following guidelines are required.

- Low-level signals, for example those from analogue sensors, that are routed outside of a screened enclosure must be transmitted differentially via shielded, twisted-pair cable.
- Appropriate design measures shall be taken to minimize the coupling, generation and radiation of interfering electromagnetic signals. These measures shall include, but not be limited to, the provision of adequate grounding and shielding and the use of appropriate robust signal transmission techniques.

3.2.1.3. Fail-safe Systems

The following provisions shall be followed in regard to fail-safe systems in the Laser System electronics.

3.2.1.3.1. Limit switches

Electromechanical or electronic limit switches, where used, shall be wired such that a break in the connecting cable to them shall cause a fault condition to exist. This precludes the use of switches wired such that the 'normally open' state indicates a 'no fault' condition.

Limit switches used for safety interlocks should be equipped with positive opening safety contacts, as well as monitoring contacts.

3.2.1.3.2. Others

Fail-safe, self checking circuits have to be incorporated in the design wherever control malfunctions or improper sequencing may create a hazard to personnel, cause personal injury or damage to equipment or parts. This circuitry should give a protection against:

a. Failure of one or more devices to function properly

b. Improper sequencing in manual or automatic operation

Control circuits incorporating position sensors, movement sensors, push buttons and similar devices should be designed in such a manner that a device must be released or otherwise returned to its reset state before it can be used to initiate a control action. The design should prevent continuous operation or cycling due to a device that has been tied down, jammed or otherwise defeated.

3.2.2. Power supply

The Laser System power supply should be 3 phase 208 VAC. If this requirement cannot possibly be met, Gemini might consider installing dedicated 480 VAC lines for the Laser System. Note that in such a case the Laser System would be the only system using this high a voltage, which would imply a major re-work on the Gemini side. The amperage available is 30A for 208 VAC.

3.3. Servo-controls

3.3.1.1. General

The Laser Guide Star System will contain a number of independent closed-loop servo and regulation systems, some of which are given in section 4.1.3. The general principles listed shall apply, where appropriate, to all such loops.

Digital control systems shall be used unless a substantive reason against is evident. Vendors should note that Gemini 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 note that Gemini recommends the use of Allan Bradley PLC5 for Programmable Logic Controllers (Ethernet option has to be considered).

3.3.1.2. Control System Design Requirements

During commissioning activities, planned maintenance, fault-finding and future upgrade work, it will be necessary for engineering staff to have low-level access to the control system loops. It is therefore required that:

3.3.1.2.1. Open-loop operation

Every closed-loop system must be capable of being operated open-loop – the purpose is to ensure that open-loop operation is available for testing and fault-finding. Where possible the switch from open to closed-loop operation should be accomplished by a software command.

3.3.1.2.2. Signal monitoring

It shall be possible to monitor, for each loop in the Laser System, the demand, response and error signals plus any others (such as disturbances or other external inputs) that are significant. At minimum, these signals shall be capable of being monitored and logged (recorded) via an Engineering Screen interface at the system sample rate. Where these signals exist as analogue voltages or currents, they shall be available for monitoring via suitable easily-accessible test points.

3.3.1.2.3. Documentation

Full design documentation for the control loops shall be provided, to include block-diagram, transfer-function models of the system, performance criteria and analyses to show how these requirements are met. Models and simulations of the control loops shall be provided. Preferred softwares for models and simulations are MATLAB and SIMULINK. Meeting of the performance targets by these simulations shall not substitute for the meeting of the same targets by the actual Laser System.

3.3.1.2.4. Software

All software associated with the control loops (source code, for example, DSP code, PMAC routines etc.) must be made available in printed and electronic form. Copies of all software installed throughout the various servo-control systems must be supplied in compiled and uncompiled source form. A list of software development tools (compilers etc.) will also be supplied. Upon delivery of the Laser System, Gemini is permitted to modify the source code as needed without permission of the vendor.

3.3.1.2.5. Low-level signals access

Low-level signals in the Laser System servo-control systems shall be accessible. This shall enable an engineer or technician to monitor signals in real-time (such as those from encoders, limit switches, sensors etc.) and issue low-level commands (such as increment a stepper-motor drive position, enable/disable a logic output etc.)

3.4. Cooling systems

3.4.1. Heat dissipation requirement

The Laser System shall dissipate to the atmosphere and mounting interface no more than 100 watts when operating in the environment specified in Table 2 (operating environment).

3.4.2. Coolant

Coolant in the form of a 40% glycol / 60 % water mixture at approximately 0 degrees C (Celsius) and 20 liters per minute shall be supplied by Gemini to remove heat from the Laser System. The Maximum rise in temperature of the coolant exiting the Laser System shall be 5 degrees C. This provides about 5KW dissipation. Laser Systems requiring more power to be dissipated need to include systems necessary for transporting waste heat approximately 100 meters and transferring it to the ambient atmosphere.

Static head on the coolant will be nominally 40 p.s.i. Temperature variation is nominally 3 degrees centigrade.

3.4.3. Protection from overtemperature

In the event of coolant circuit failure, some form of protection from overheating must be provided.

3.5. Software

3.5.1. General

The Laser System will have its own Control System made of hardware and related software. This system must be able to control the Laser System remotely. Specifically all Laser System controls, commands and all signals specified below must be accessible from the control room of the Gemini North telescope. The Laser System Control System functional requirements are described in section 3.5.2. The Laser System Control System shall also interface with the LGS Control System and the Synchro-Bus. All interface requirements are described in section 3.5.3.

3.5.2. Laser System Control System functional requirements

The Laser System must provide the following:

- The Laser System must accept commands for its functions from the control room and provide completion information for successful commands and error or warning conditions for failing commands.
- The Laser System must provide remote control of all its mechanisms, with access to all parameters of its servo loops as well as control of specific and complex sequences of elementary tasks. Mandatory tasks are listed in the following section 3.5.2.1.
- If pulsed at a repetition rate between 600 Hz and 1 kHz, the Laser System shot to shot pulses must be controllable from an external signal (see sections 3.5.3.2.3 and 4.1.4.1).
- The important status information describing the state of the Laser System and all diagnostics parameters must be available for display in the control room and data-logging. It must be possible to monitor all Laser System status information at the rate of once per second or faster without burdening the Laser System hardware. All diagnostics parameters will be available for real-time display as well at a realistic rate between 0.5 second and 10 second. Profiles will be diplayed once per minute or faster. A system whereby the Laser System notifies of changes in status is preferable to a polling approach. Each status item must be time-stamped with a time indicating when the status value was valid.
- The Laser System must notify the user in the control room when a status variable enters an alarm condition.

3.5.2.1. Elementary tasks and sequences

The mandatory tasks and sequences provided with the Laser System are those described in the Laser System operation requirements, section 4. Among them:

- Prior-to-start internal check (4.1.2.1)
- Automated start-up(4.1.2.2)
- Automated shutdown(4.1.5.1)
- Emergency shutdown(4.1.5.2)
- Control on the output power level - if possible (4.1.4.2)
- Wavelength tunability - if required by the laser pulse format (4.1.4.3)
- Control on the laser shutter (3.6.3.4)

3.5.2.2. Diagnostics parameters

The following parameters must be available for real-time display in the control room. The sections which describe the corresponding requirements are given in parenthesis.

- Output power (4.2.1)
- Spectral characteristics (4.2.2)
    - Central frequency
    - FWHM
- Temporal profile - if the laser is pulsed (4.2.3)
- Spatial profiles (4.2.4)
    - Near-field
    - Far-field
- Beam quality – can be derived from the spatial profile measurements (4.2.5)
- Laser System internal status (4.2.6)
- Temperature in the Laser Enclosure (4.2.7)
- Coolant (4.2.8)
    - Temperature
    - Flow rate
- Accumulated hours (4.2.10)

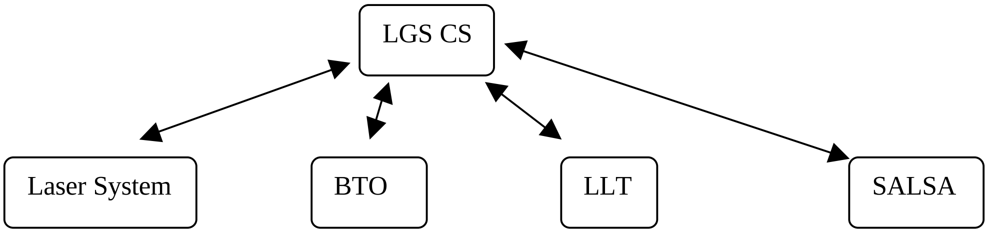
3.5.2.3. Data-logging

It must be possible to log all status information and diagnostics parameters into an ASCII file for maintenance and debugging purposes. All information shall be time-stamped.

3.5.3. Laser System Control System interfaces

3.5.3.1. General environment

The Laser Guide Star Control System, which will be created by Gemini, will be an EPICS/VxWorks system based on VME crate. It will interface independently with each of the four subsystems of the LGS system as shown in the schematic below. A more detailed description of the LGS Control System and its interfaces with other Gemini systems is given in appendix (f).



3.5.3.2. Interface requirements

3.5.3.2.1. Remote control

The Laser System will be remotely operated and controlled from the Gemini North telescope control room. This must be done through the Ethernet.

3.5.3.2.2. Interface with the LGS Control System

The Laser System vendor must provide a hardware control system and software communication mechanism for use between the EPICS LGS CS and the Laser System that both parties agree can be integrated with the EPICS based LGS CS. Examples of these include network protocol (Channel Access from EPICS), communication through the Synchro-Bus, etc.

There are at least two functions among those listed in section 3.5.2 which must be available to the LGS Control System and/or must support commands from it. These functions are:

- wavelength tunability – the Laser System Control System must be able to support the detune/re-tune procedure command when sent by the LGS Control System
- safety systems – the Laser System Control System must notify the LGS Control System when there is an alarm related to personnel and/or material safety. The Laser System must also be able to answer an emergency shutdown notice.

3.5.3.2.3. Special interface requirement for pulsed laser systems

Pulsed laser systems which have a repetition rate between 600 Hz and 1 kHz will have to interface with the Gemini Synchro-Bus. Reasons for this synchronization requirement are given in section 4.1.4.1. Other laser systems are not concerned by this requirement.

The ALTAIR Adaptive Optics system will make available the exact time when the Laser System must output a pulse on the Synchro-Bus. This information will be made available on the Synchro-Bus at a rate equal to ALTAIR laser WFS frame rate (up to 1 kHz).

3.5.3.3. Laser System Control System goals

It is highly desirable that all elementary tasks and sequences, as well as all diagnostics parameters will be made available to the LGS CS through the interface between the Laser System Control System and the LGS CS. The purpose of stating this as a goal instead of a requirement is not to rule out vendors who would consider too difficult to develop a global interface with EPICS. However vendors should be aware that Gemini is interested in discussing cost effective ways to implement more than the minimum required interface. **Gemini is open to proposals for a Laser System fully interfaced with the LGS CS.**

To fulfill the goal, the Laser System vendor would have to provide all hardware and software needed to send these signals through the interface with the LGS CS VME crate. Gemini would remain responsible for the VME crate, the interface of VME boards with the Laser System, the EPICS database, all dedicated drivers to accomplish communication between the hardware and the EPICS database, and all the engineering screens to control the Laser System. The software/hardware requirements related to the Laser System would be the same as described in section 3.5.2.

3.5.4. Laser System set-up

During set-up, engineering time or for diagnostics purpose, the Laser System should provide low level access and control using a PC, laptop or other computer. It should be possible to perform at least all functional tasks described in section 3.5.2 while working on the Laser System set-up at the laser head location. If necessary, it should be possible to perform additional tasks during the Laser System set-up.

3.5.5. Laser System Reliability and Recoverability

The Laser System software should run reliably under normal operation mode or observing procedures for lengths of time equal to or greater than one observing night (12 hours) without requiring any reinitialization. The Laser System should recover from any kind of software failure without reinitializing the Laser System hardware.

3.5.6. Software sources

All software source codes must be made available in printed and electronic form. Copies of all software installed throughout the Laser System must be supplied in compiled and uncompiled source form. A list of software development tools (compilers etc.) will also be supplied. Upon delivery of the Laser System, Gemini is permitted to modify the source code as needed without permission of the vendor.

3.6. Safety

3.6.1. General

The design, fabrication, assembly and maintenance will be consistent with safe working practice. All applicable established standards and guidelines must be adhered to.

3.6.2. Applicable standards

The Laser System must comply with:

- all applicable OSHA guidelines
- the American National Standard for the Safe Use of Lasers, ANSI Z136.1-1986
- the FDA's Laser Products Performance Standards, 21 CFR 1040.10 and 1040.11
- the Electrical Standard for Industrial Machinery NFPA 79

See for instance http://www.osha-slc.gov/OshDoc/Directive_data/PUB_8-1_7.html

3.6.3. Miscellaneous

3.6.3.1. Insulating materials

Foams used for insulation must be flame retardant and of the closed cell variety.

3.6.3.2. Electronics cabinets

Special attention will be taken regarding safety related to possible electrical hazards. For instance:

- The Laser System should be supplied by a single electrical power source. Control enclosure should be equipped with manually operated, readily accessible, main disconnect switch.
- When the control enclosure door is closed, the operating handle shall positively indicate whether the disconnecting means is in the open (off) or closed position.
- There should be no exposed live parts when the main disconnecting switch is in the open position.

3.6.3.3. Laser System start-up

As stated in section 4.1.2.2, the Laser System start-up procedure must be fully automated. However it will be necessary that someone goes to the laser location and turns a key on the system to allow this procedure to take place. If the key has not been turned, the Laser System will not start.

3.6.3.4. Laser shutter

The Laser System must have a mechanical shutter at the output of the laser. The shutter will block the laser radiation when needed. It will be able to absorb the laser full power for more than 12 hours. Note that this shutter is NOT the final *safety shutter* that Gemini will implement and integrate as part of the SALSA subsystem of the LGS system later on.

3.6.3.4.1. Laser System set-up

The shutter will have the capability to be open/closed manually and under control of the Laser System Control System.

3.6.3.4.2. LGS AO operation

The shutter will be controlled by the Laser System Control System.

3.6.3.5. Fire detection

If the Laser System makes use of inflammable materials it should have an appropriate fire detection system.

3.7. Interlocks

3.7.1. Internal to the Laser System

3.7.1.1. Laser System operation

For those sequences of actions which have to be taken in a pre-defined order, there will be interlocks to make sure that they are taken in the right order. This requirement is especially strong if the Laser System contains parts that could be damaged in case the actions would be taken in the wrong order.

3.7.1.2. Access panels

It should not be possible to access either the inside of the laser enclosure nor the electrical power supply to the laser head when the Laser System is working. To accommodate this requirement, all access doors are to be equipped with locking style safety interlock switches.

3.7.2. Interface with the Gemini Interlock System (GIS)

It must be possible to integrate the Laser System with the Gemini Interlock System (GIS). All critical functions that could need integration with the GIS must be made available by the Laser System.

The Laser System must also be designed so that it can be interfaced with the existing telescope emergency stop system. Emergency stops of the laser system have to be integrated with the existing telescope Emergency Stop circuit. The Laser System emergency stops and existing telescope/Dome Emergency stops have to be functionally identical. Reset of the emergency stop (or any other fault condition) must not initiate a restart cycle.

See section 4.1.5.2 for related information on the Laser System emergency shutdown.

3.7.3. Personnel safety

Personnel safety interlocks should have only hardwired electromechanical components. Operation of safety interlock should not depend on electronic logic (hardware or software) or the transmission of commands over a communication network or link.

3.8. Lifetime

The Laser System must have a functional lifetime of at least 3 years of operation at no less than 2200 hours of operation per year. This means that the Laser System must meet the performance, maintenance, and other requirements given in this document for this time.

3.9. Maintenance & staffing

3.9.1. *Maintenance*

3.9.1.1. Operation and Maintenance Manual

Vendors will provide an Operation and Maintenance Manual that will include:

a) System description and drawings, parts list

b) Assembly instructions

c) Operating instructions

d) Maintenance schedule with suggested spares list

e) Test results from acceptance tests

3.9.1.2. Optics cleaning

The optics of the Laser System will be protected from dust or any other type of contamination from the environment by some appropriate covers. Assuming that no contamination happens, there will be not need to clean the optics more than once a month. All optics will be easy to access in order to be cleaned without removing them from their mounts. If some optics need to be replaced, it will be easy to do so.

3.9.1.3. Other components

All the components of the Laser System will be easy to access in case they should be maintained, repaired or replaced.

3.9.2. *Failures*

3.9.2.1. Mean-time between failures (MTBF)

3.9.2.1.1. Critical failures

Critical failures occur when the Laser System has to be serviced by a laser specialist or by the vendors.

MTBF > 900 hours of operation

3.9.2.1.2. Minor failures

Minor failures occur when the Laser System can be serviced by a laser technician.

MTBF > 100 hours of operation

3.9.3. *Gemini staffing*

3.9.3.1. Maintenance & repair

A Gemini laser technician must be able to maintain the laser system. This shall not require more than 3 days of work per week (goal is one day of work per week, once every other week). The laser shall not need to be removed from its location to perform any maintenance tasks. In case of minor failure, the laser technician shall be able to fix the Laser System within no more than a day.

3.9.3.2. Laser System start-up

The Laser System start-up will be performed by a non-laser specialist. All start-up tasks must be automated and performed remotely (see section 4.1.2).

3.9.3.3. For nightly operation

The Laser System must perform reliably during every night of observation (12 hours). It shall need neither adjustment nor service during observation time.

4. Laser System operation requirements

4.1. During LGS operation and/or LGS AO observation

4.1.1. General requirement

The Laser System operation must be fully automated. For those sequences of actions which have to be taken in a pre-defined order, there must be interlocks and alarms to make sure that they are taken in the right order. This requirement is crucial if the Laser System contains parts that could be damaged in the event that the actions were taken in the wrong order.

4.1.2. Start-up procedure

4.1.2.1. Prior to start internal check

The Laser System must execute an automated internal check each time before the Laser System is run. The internal check will be a single command provided by the Laser System Control System. The result of the internal check will be displayed. The Laser System shall not be started unless the internal check returns no error or warning.

4.1.2.2. Automated start-up

The Laser System start-up will be automated. There will be an automated sequence of actions to start the Laser System and power it up to its full power level. The start-up sequence will be provided as a single command by the Laser System Control System. Each individual steps of the sequence will be available as well.

4.1.2.3. Start-up time

The Laser System Start-up time will be no longer than 30 minutes, including internal check.

4.1.3. Closed loops

The following parameters shall be under closed-loop control:

- Optical alignment of the laser cavity
- Central frequency of the laser spectrum
- Output power
- Beam pointing
- Output beam location

- Beam divergence
- Laser enclosure temperature

4.1.4. Other controls

4.1.4.1. Synchronization of pulsed laser systems

Pulsed laser systems with a repetition rate between 600 Hz and 1 kHz will be externally synchronized at a fixed rate. This rate will be equal to the ALTAIR laser WFS frame rate. The synchronization will allow for some low frequency drift of the pulse shot to shot intermediate time due to changes in the round trip time of light during operation. The Laser System might have to take the shot to shot time drift into account before each pulse. The exact time when the laser pulse will have to be fired will vary by no more than 0.2 μsec/second. It might also happen that the Laser System has to update the repetition rate once every 10 seconds only. This would then correspond to a shot to shot time-drift no longer than 2 μsec every 10 seconds.

See section 3.5.3.2.3 for related interface requirements.

4.1.4.2. Output power

The laser output power will be adjustable (laser technology permitting).

4.1.4.2.1. Low power

There should be a ‘low power’ mode for the laser output power. The low power mode will be used for alignment of the LGS system (Laser System + BTO + LLT). The low-power level will be 100 mW ± 20 mW.

4.1.4.2.2. Full power

During the Laser System set-up and normal operation, the laser output power should be adjustable by steps of 2% of the full power level. The adjustable power range will span over 20% of the maximum power level. The adjustments will be controlled by the Laser System Control System.

4.1.4.3. Tunability

Rayleigh scattering can be time-gated for pulsed laser systems with repetition rates between 600 Hz and 1 kHz. When Rayleigh scattering cannot be time-gated, laser systems must be able to shift frequency out of the sodium D2 line so that the Laser Guide Star disappears and Rayleigh scattering can be calibrated by the LGS AO system.

All laser systems but pulsed lasers with repetition rates between 600 Hz and 1 kHz will have the possibility to shift the central frequency ν_0 out of the sodium D2 by a quantity $\Delta\nu$. The tunability requirement is:

$5 \text{ GHz} < \Delta\nu < 500 \text{ GHz}$.

The detuning procedure away from ν_0 back to ν_0 will be automated and it will not take more than 10 seconds. The procedure will be a single command provided by the Laser System to the LGS Control System.

4.1.5. Shut-down procedures

4.1.5.1. End of operation shutdown

At the end of normal operation, there will be an automated sequence of actions to shutdown the Laser System. The Laser System automated shutdown will be initiated by the Laser SystemControl System and provided as a single command. Each of the individual steps of this sequence will be available to the Laser System Control System as well.

The laser shutdown will take no longer than 30 minutes.

4.1.5.2. Emergency shutdown

There will be the possibility to shut the Laser System down in case of an emergency. The Laser System shall have the capability of being shut down manually and under control by the LGS Control System. An emergency shutdown command will be provided as a single command by the Laser System to the LGS CS. There will be an emergency button close to the laser head location or on top of the laser enclosure itself. The Laser System will also be connected to the emergency button that can stop the telescope and the dome in case of an emergency.

The emergency shutdown will take no longer than 1 second. Everything in the Laser System that can be shut down without damaging optical parts or other parts will be. If a full shutdown can cause possible damages to optical parts or other parts of the Laser System, there will be an automated procedure to complete the emergency shutdown on top of the one second requirement. For instance the cooling system may have to continue to work for some period of time.

4.2. Diagnostics

All diagnostics listed below must be part of the Laser System. Any other diagnostics required for the operation of the Laser System must also be included. Requirements regarding measurement units and precision are given in the following. Note that all measured parameters must also be time-stamped.

Software requirements related to diagnostics are given in section 3.5.

4.2.1. Output power

The total laser output power shall be monitored. The output power at 589 nm shall be monitored as well. Both measurements will use calibrated power sample as opposed to absolute measurements. Therefore there will be no moving parts in the Laser System design. Power-meter calibration curves will be provided.

Unit: Watt

Precision: ± 50 mW

Output: Total power value & 589 nm power value & Time-stamp

4.2.2. Spectral characteristics

The central frequency of the laser spectrum and its FWHM shall be monitored.

- **Central frequency**

Unit: MHz

Precision: ± 50 MHz

Output: Comparison with the sodium D2 line & Value & Time-stamp

- **FWHM**

Unit: MHz

Precision: ± 1 MHz for monomode lasers / ±50 MHz for multimode lasers

Output: Spectrum profile & FWHM value & Time-stamp

4.2.3. Temporal profile

This requirement concerns pulsed lasers only. Pulsed laser systems shall provide a test point for monitoring the pulse temporal profile (e.g. with a fast photodiode looking at a beam sample). If the laser is macro-micro pulsed, it shall be possible to measure both macro-pulse and micro-pulse profiles.

Unit: consistent with the laser temporal format

Precision: ± 5 %

4.2.4. Spatial profiles

Both the near-field and far-field profiles of the laser beam shall be monitored. The beam quality shall be either derived form those profiles or measured as well.

4.2.4.1. Near field

This is the measurement of the profile of the beam at the output of the laser.

Xunit: µm; Yunit: Watt/area

Xprecision: ± 50 µm; Yprecision: ± 1 %

Output: Profile & FWHM value & Time-stamp

4.2.4.2. Far field

This is the measurement of the profile of the laser beam propagated to the far field.

Xunit: µrad & arcsec; Yunit: Watt/solid angle

Xprecision: ± 0.2 µrad i.e. ± 0.05 arcsec; Yprecision: ± 1 %

Output: Profile & FWHM value & Time-stamp

4.2.5. Beam quality

Using the beam profiles in the near field and far field, there shall also be a measurement or calculation of the encircled energy as defined in section 2.3.5.3. The value of the beam $1/e^2$ angular diameter in the far field, $2\ \theta_0$, will be monitored as well as the value of the encircled energy at $\theta = \theta_0$ where θ is the divergence angle.

$\theta_0 = 1/e^2$ angular diameter in the far field

Unit: µrad & arcsec

Precision: ± 0.2 µrad i.e. ± 0.05 arcsec

Output: Value & Time-stamp

EE ($\theta = \theta_0$) = encircled energy

Unit: %

Precision: ± 1 %

Output: Value & Time-stamp

4.2.6. Laser System internal status

The Laser System internal status shall be monitored. No detailed requirements are given here since they depend strongly on the laser system that will be proposed by the vendor. However vendors are requested to list the elements that will need some level of diagnostics in order for the laser system to work reliably and safely. The list will be discussed later on.

4.2.7. Temperature in the laser enclosure

The temperature in the laser enclosure shall be monitored.

Unit: Celsius degree

Precision: ± 0.5 Celsius degree

Output: Value & Time-stamp

4.2.8. Coolant

The temperature and flow rate of the coolant shall be monitored for all cooling systems of the Laser System.

- **Temperature**

Unit: Celcius degree

Precision: ± 0.5 Celcius degree

Output: Value & Time-stamp

- **Flow-rate**

All the cooling systems of the Laser System must have a flow sensor.

Output: Value & Time-stamp

4.2.9. Polarization

It should be possible to measure the laser polarization off-line. This is not a requirement but a goal.

4.2.10. Accumulated hours

The number of hours of laser operation will be monitored.

4.3. Laser enclosure

A laser enclosure must be part of the Laser System. The laser enclosure will house the laser head.

4.3.1. Temperature

The laser enclosure temperature will be close to 20 Celsius (ambient temperature in a laboratory). The temperature inside the enclosure will be maintained whatever the status of the Laser System (operation or shutdown) and whatever the outside temperature. The purpose is to keep the laser head away from temperature gradients that may alter its performance. However the laser enclosure may have to be open when sitting in an environment whose temperature is different from the inside temperature (typically, if it has to be open while sitting on the telescope or elsewhere in the dome). In such circumstances, the Laser System shall keep up with the change in temperature and adjust so that the next time it is used the Laser System still meets the performance requirements described in section 2. The elapsed time for the Laser System to adjust to the change in temperature will be no more than 2 hours.

The temperature will be automatically controlled and kept stable to within ± 0.5 Celsius degree.

4.3.2. Vibrations

The laser head shall be isolated from the vibrations created by the telescope or the dome during day and night time operation. The Laser System optics shall be mounted on a bench or table which efficiently isolates them from vibrations so that the Laser System performs reliably whatever its location in the dome. This requirement is dependant on the possible laser head locations (see section 1.4.2). More quantitative information on the vibration power spectrum at any possible location for the laser head will be available during the final design process of the Laser System.

The Laser System must be isolated form the telescope vibrations, but it is also a requirement that the Laser System must not create any vibrations that could be transmitted to the telescope.

4.3.3. Output beam

4.3.3.1. Output location

If the laser head is to be mounted on the telescope, then the output beam location will be on the right side of the laser enclosure when standing in front of it (laser enclosure mounted on the telescope at location A or B).

4.3.3.2. Window

The laser enclosure will be sealed by an optical window so that there is no air turbulence created by warm air flowing out of the laser enclosure (no 'chimney' effect).

4.3.3.3. Beam steering

Gemini will need to implement at least three elements at the beginning of the BTO path, just after the Laser System output aperture. These elements are the safety shutter (to be integrated with the SALSA subsystem of the LGS system), a quarter wave plate to change the laser polarization from linear to circular (or slightly ellipsoidal) and the first steering mirror of the BTO mirror train. No precise requirement can be written relative to the mechanical interface between the Laser System and the BTO yet, until the laser head location is known. However, vendors are required to propose a plan describing how the laser enclosure will be interfaced with these first BTO elements.

4.3.4. Ease of access

When standing in front of the laser enclosure, it will be possible to access anything that is inside the enclosure by removing:

- the facing vertical cover of the laser enclosure if the laser head is mounted on the telescope
- the top of the laser head enclosure if the laser is mounted horizontally on a bench or table.

All parts (optics, mounts, diagnostics, electronics, etc.) will be easily accessible. Vendors are required to provide other adequate access panels for this purpose.

5. References

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6. Appendices

(a) Telescope overview (f/16 top-end) – AutoCAD drawing
(b) Possible laser path from location B – AutoCAD drawing
(c) Laser locations space envelopes drawings
    (c1) Possible laser locations – AutoCAD drawing
    (c2) Laser system space envelope, location A – AutoCAD drawing
    (c3) Laser system space envelope, location B – AutoCAD drawing
    (c4) Laser system space envelope, location B’ & C – AutoCAD drawing
    (c5) Laser system space envelope, location H – AutoCAD drawing
    (c6) Laser system space envelope, location J – AutoCAD drawing
    (c7) Laser system space envelope, location K – AutoCAD drawing
(d) Sodium D2 line
(e) *Gemini Mauna Kea Laser Guide Star System*, Céline d’Orgeville et al., *Adaptive Optics Systems and Technology*, SPIE Proc., vol. 3762, 1999
(f) Laser Guide Star Control System