THIRTY METER TELESCOPE

SUBSYSTEM REQUIREMENTS DOCUMENT

FOR

THE LGSF LASER SYSTEM

TMT.AOS.DRD.09.003.DRF05

August 25, 2009

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1. INTRODUCTION

1.1 INTRODUCTION

This is the Laser Guide Star Facility (LGSF) Laser System Design Requirements Document (DRD). The requirements in this document flow down from the LGSF DRD document [AD4].

1.2 PURPOSE

The purpose of this document is to provide a comprehensive definition of the Laser System requirements.

The intended audience for this document is primarily the developers and reviewers of the Laser System.

1.3 SCOPE

The Laser System is a sub-system of the TMT LGSF. It provides the light sources for generating the artificial stars in the sodium layer at 90 – 110 km altitude for the TMT Adaptive Optics (AO) systems.

At first light, the Laser System will provide the light sources necessary for generating the artificial stars of the TMT Narrow Field InfraRed Adaptive Optics System (NFIRAOS) asterism. NFIRAOS is a Laser Guide Star (LGS) Multi Conjugate AO (MCAO) system, which feeds up to 3 science instrument ports after sensing and correcting for wavefront aberrations introduced by atmospheric turbulence and the telescope itself.

The Laser System will be eventually upgraded to generate the asterisms for all the future TMT Laser Guide Star (LGS) AO systems[1]. At least two levels of upgrade are foreseen:

- The first upgrade will enable the asterism required by the Multi Object Adaptive Optics (MOAO) instrument. Note that the first light Laser system will enable not only the NFIRAOS MCAO asterism but also the Mid IR Adaptive Optics (MIRAO) and Ground Layer Adaptive Optics (GLAO) asterisms.
- The second upgrade will enable the brighter LGS required by the 120x120 order version of the NFIRAOS MCAO system. Further upgrades are not known.

The scope of this document is limited to the first light Laser System and the first upgrade. Upgrading the Laser System to generate the brighter LGS required by the 120x120 order version of the NFIRAOS MCAO system will require different laser technologies.

The Laser System does not include either the system to transport and launch the laser beams to the sky, or the laser safety systems.

Section 1 contains information about this document. Section 2 contains information about the LGSF Laser system and Section 3 contains the requirements. Paragraphs in Section 3 marked as "Discussion" are for information only and are not requirements.

1.4 APPLICABLE DOCUMENTS

[1] TMT has defined 4 future LGS AO instruments at the moment: (1) a Mid InfraRed AO (MIRAO) system, which requires 3 LGS, (2) a Ground Layer AO (GLAO) system, which requires 5 LGS, (3) a Multi Object AO (MOAO) System, which requires 8 LGS and (4) a 120x120 order version of the NFIRAOS MCAO system, which requires 6 brighter LGS.

AD1 Operations Concept Document (OCD), (TMT.OPS.MGT.07.002)

AD2 Observatory Requirements Document (ORD), (TMT.SEN.DRD.05.001)

AD3 Observatory Architecture Document (OAD), (TMT.SEN.DRD.05.002)

AD4 LGSF Design Requirement Document, (TMT.AOS.DRD.08.003.REL02)

1.5 CHANGE RECORD

Revision	Date	Section	Modifications
DRF01	May 7, 2009	All	C. Boyer: Initial draft
DRF02	May 21, 2009	All	C. Boyer: Solve TBD and interface definitions, include BE comments
DRF03	June 8, 2009	3.2, 3.3.5, 3.4.1, 3.4.2, 3.5 and 3.6.1	C. Boyer: Modify [REQ-3-LAS-0810], [REQ-3-LAS-0820], [REQ-3-LAS-1440], add [REQ-3-LAS-1560] and [REQ-3-LAS-1570], modify [REQ-3-LAS-1710]. Update section 3.6.1.
DRF04	June 18, 2009	1.3, 3.2, 3.3.4, 3.4.2	C. Boyer: Modify [REQ-3-LAS-0200], [REQ-3-LAS-0700], [REQ-3-LAS-1570]
DRF05	August 24, 2009	2.6, 3.2, 3.3.1, 3.3.2, 3.3.3, 3.4.1, 3.4.3, 3.6.1	C. Boyer: Modify discussions of [REQ-3-LAS-0200] and [REQ-3-LAS-0210]. Modify [REQ-3-LAS-0250], [REQ-3-LAS-0310], [REQ-3-LAS-0320], [REQ-3-LAS-0330], [REQ-3-LAS-0350], [REQ-3-LAS-0410], [REQ-3-LAS-0430] and discussion, [REQ-3-LAS-0440] and discussion, [REQ-3-LAS-0510] and discussion, [REQ-3-LAS-0520] and discussion, [REQ-3-LAS-0560], [REQ-3-LAS-1440], and discussion of [REQ-3-LAS-1820]. Add [REQ-3-LAS-0441], [REQ-3-LAS-0511], [REQ-3-LAS-0521].

1.6 ABBREVIATIONS

ACRS – Azimuth Coordinate System

AG – Asterism Generator

AGCM – Asterism Generator Centering Mirror

AGPM – Asterism Generator Pointing Mirror

AO – Adaptive Optics

AOESW – AO Executive Software

AOSQ – Adaptive Optics Sequencer

AZFA – Azimuth Optical Path Fold Array

AZOP – Azimuth Optical Path

BDM – Beam Dump Mirror

BS – Beam Splitter

BTO – Beam Transfer Optics

CW – Continuous Wave

DM – Deformable Mirror

DMS – Data Management System

DFA – Deployable Fold Array

DPA – Deployable Pointing Array

DRD – Design Requirements Document

DTRA – Deployable Tracking Array

ECRS – Elevation Coordinate System

FF – Far Field

FoV – Field of View

FSM – Fast Steering Mirror

GLAO – Ground Layer Adaptive Optics

GUI – Graphical User Interface

ICD – Interface Control Document

IRMOS – InfraRed Multi Object Spectrograph

LAS – Laser System

LGS – Laser Guide Star

LGSF – Laser Guide Star Facility

LIS – Laser Interlock System

LSQ – Laser Sequencer

LSS – Laser Safety System

LLT – Laser Launch Telescope

LOM – Laser Output Mirror

MCAO – Multi Conjugate Adaptive Optics

MIRAO – Mid IR Adaptive Optics

MOAO – Multi Object Adaptive Optics

MTBF – Mean Time Between Failure

N/A – Not Applicable

NFIRAOS – Narrow Field Infrared Adaptive Optics System

NF – Near Field

OAD – Observatory Architecture Document

OCD – Operations Concept Document (Level 1 document)

OCDD – Operational Concept Definition Document

ORD – Observatory Requirements Document

PAC – Pre-Alignment Camera

QA – Quality Assurance

RMS – Root Mean-Square

SFG – Sum Frequency Generation

SHG – Second-Harmonic Generation

SMP – Software Management Plan

STR – Telescope Structure

TBC – To Be Confirmed

TBD – To Be Defined

TCA – Truss Centering Array

TFA – Truss Fold Array

TMT – Thirty Meter Telescope

TREL – Truss Relay Lenses

TRIFA – Tripod Fold Array

UI – User Interface

ULAO – Up Link AO

UPS – Uninterruptible Power Supply

WFS – Wavefront Sensor

2. OVERALL DESCRIPTION

2.1 PERSPECTIVE

The LGSF is composed of 3 main sub-systems:

(i) The Laser System (LAS), which includes the lasers and all associated control systems. The Laser System is located within the ($-X_{ACRS}$, $-Y_{ACRS}$) quadrant of the telescope azimuth structure (see Figure 3). The Laser System provides the light sources for generating the artificial stars in the sodium layer at 90 – 110 km altitude. The Laser System is the subject of this requirement document.

(ii) The Beam Transfer Optics (BTO) and Laser Launch Telescope (LLT) System, which is responsible for taking the beams from the output of the Laser System and transferring them across the telescope azimuth structure, up the telescope elevation structure and then launching them from the LLT located behind the TMT secondary mirror. The BTO/LLT System is composed of two principal systems: (1) the BTO Optical Path and (2) the LGSF Top End, which consists of BTO and LLT components located behind the TMT secondary mirror.

(iii) The Laser Safety System (LSS), which is itself composed of several sub-systems dedicated to:

a. Protecting people and observatory systems from laser light,

b. Protecting aircraft from laser illumination,

c. Protecting neighboring telescopes (if any) from laser beams within their field of view, when necessary.

The LGSF optical block diagram is given in Figure 1:

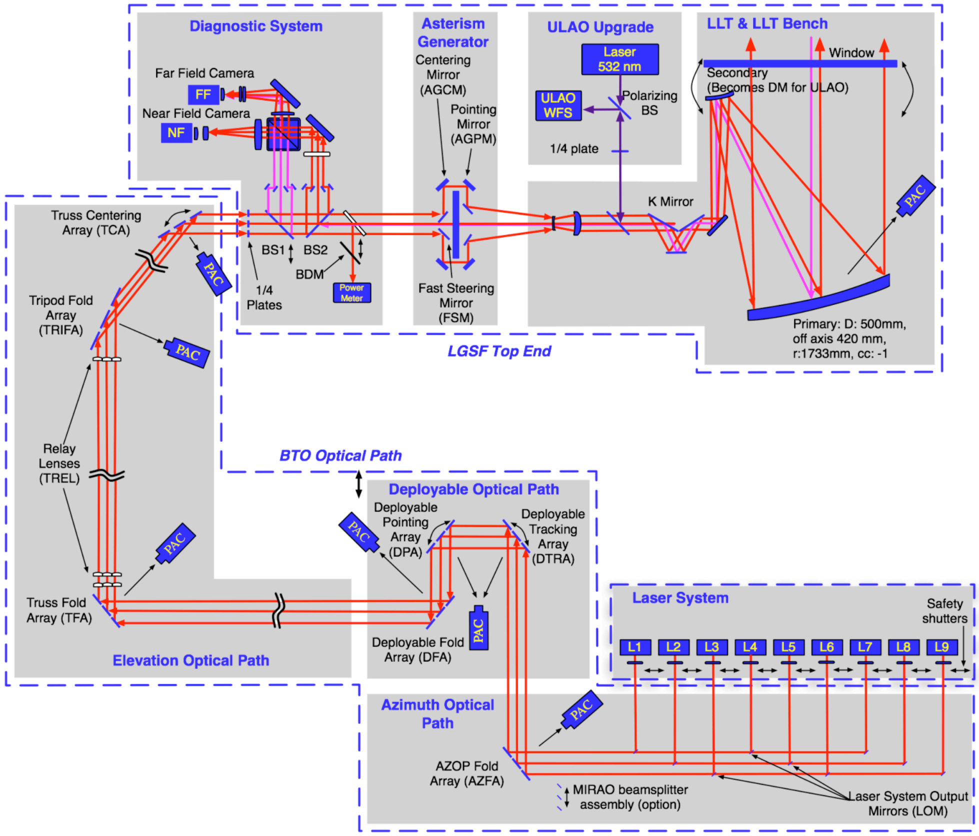

Figure 1: LGSF Optical Block Diagram

2.2 SYSTEM FUNCTIONS

The Laser System will provide the following system functions:

- Generate the laser light sources required for the NFIRAOS asterism with the proper power level, spectral and temporal characteristics, and image quality.
- Be upgradeable to generate the laser light sources needed by the MOAO system.

2.3 USER AND OPERATOR CHARACTERISTICS

The Laser System is under the software control of the AO Sequencer (which is a sub-system of the AO Executive Software) during daytime and nighttime operations. These operations include startup, observation, and shutdown operation modes.

The users of the Laser System are:

- The laser technicians and laser engineers. During commissioning operations, the laser technicians/engineers perform all the functions required to start the Laser System, optimize performance before the LGS observations, monitor and maintain the Laser System performance during observations and then shutdown the Laser System at the end of the LGS observations. During scheduled maintenance periods, the laser technicians/engineers perform all the maintenance activities required by the Laser System.

- The telescope operators. During normal science operations, the laser technicians/engineers perform all the functions required to start the Laser System during daytime activities and the telescope operators perform all the functions required to monitor the Laser System performance, and shut down the Laser System at the end of observations. All of these operations will be performed through the TMT high-level executive software, which will interface automatically with the Laser System.

2.4 EXTERNAL INTERFACES

The LGSF Laser System interfaces with several other observatory systems, including but not limited to:

- The other LGSF sub-systems, including:
    i. The Laser Safety System
    ii. The Beam Transfer Optics and Laser Launch Telescope System
- The Telescope Structure (STR)
- The AO Executive Software (AOESW)
- The Data Management System (DMS)

These interfaces are described in more details in section 3.6.

2.5 CONSTRAINTS

The Laser System software shall comply with the TMT Observatory software standards and software development processes to be specified in the TMT Software Management Plan (SMP). This plan is not complete at the time, but it will cover the following areas:

- The software management process (software life-cycle and milestones, software documentation, software risk management, configuration control management…).
- The software development process (requirements, design, implementation, framework, tools and standards, delivery and maintenance…). Preliminary standards have been defined in some cases, particularly for the real time systems. Some of these preliminary standards include the choice of:
    i. Software development/deployment platforms: VxWorks and RT-Linux (Red Hat, Novell)
    ii. Implementation language: C, Embedded C++, JAVA RTS
- The software verification and validation process (QA, review process, integration and test, assembly and verification…).

The Laser System shall comply with the safety regulations and processes to be defined in the TMT Laser Safety Program Document. This document is not complete at this time, but it will cover the following areas:

- Safety responsibilities,
- Laser safety procedures,
- Laser standard operating procedures (operations, controls, registrations, training and incident reporting).

2.6 ASSUMPTIONS AND DEPENDENCIES

It is assumed that the Laser System is composed of several identical Laser Units and one Laser Sequencer. Each Laser Unit consists of one Laser Head and one Laser Controller.

The number of Laser Units is defined as follows and in requirements [REQ-3-LAS-0310] and [REQ-3-LAS-0330]:

- First Light Laser System: six plus one spare (seven total) Laser Units to generate the NFIRAOS asterism. The First Light Laser System will also generate the MIRAO and GLAO asterisms.
- Final Laser System: eight plus one spare (nine total) Laser Units to generate the MOAO asterism.

Although only seven Laser Units are required at first light, the Laser System shall be designed to be upgradeable to include nine Laser Units.

The role of the Laser Sequencer is to coordinate the actions of the multiple Laser Controllers and to interface with the AO Sequencer.

The Laser Units shall also work as autonomous systems and include for example engineering user interfaces for engineering maintenance purposes.

3. SPECIFIC REQUIREMENTS

3.1 GENERAL REQUIREMENTS

3.1.1 Standards Requirements

[REQ-3-LAS-0010] The Laser System shall be designed for maintainability, including the use of standard components where possible, and standardization on metric hardware.

[REQ-3-LAS-0020] The Laser System software shall eventually comply, to the greatest extent possible, with the TMT Observatory software standards and software development process specified in the TMT Software Management Plan.

Discussion: The TMT Software Management Plan is not yet available. Please refer to section 2.5 for further details.

3.1.2 Sub-system Decomposition Requirements

[REQ-3-LAS-0100] The Laser System shall contain the following sub-systems:

- Up to nine Laser Units. Each Laser Unit consists of a Laser Head and a Laser Controller.
- One Laser Sequencer.
- And one Laser Cooling System (if necessary).

Discussion: The Laser Cooling System is optional. This additional system will be required if the Observatory cooling system does not meet the Laser System requirements.

3.2 ENVIRONMENTAL CONSTRAINTS

[REQ-3-LAS-0200] The Laser System shall be able to operate and meet the requirements at altitudes varying between 0 meters and 4050 meters.

Discussion: The TMT Observatory has selected Mauna Kea, Hawaii for its site.. The altitude of the Mauna Kea TMT site is 4050m. In addition, the Laser System will be operated at the LGSF and/or Laser vendor facilities, which are expected to be at much lower altitudes.

[REQ-3-LAS-0210] The Laser System shall be able to operate and meet all the requirements at temperatures varying between 271.4 K (-2 °C) and 295.15 K (22 °C) and at any non-condensing humidity conditions.

Discussion: The ambient temperature for Mauna Kea is 271.4 K to 280.8 K (-2 ℃ to 8 ℃). In addition, the Laser System will be operated at typical room temperature at the LGSF and/or Laser vendor facilities 295.15 K (22 ℃).

[REQ-3-LAS-0220] The Laser System shall be able to operate in servicing and maintenance mode at temperatures varying between 268 K (-5 °C) and 298 K (25 °C) and at any non-condensing humidity conditions.

[REQ-3-LAS-0230] The Laser System shall be able to survive without damage the operational basis survival conditions with temperatures varying between 268 K (-5 °C) to 298 K (25 °C) and humidity varying between 0% and 100%.

Discussion: Although condensing conditions are specified, it is not expected that precipitation is falling within the dome.

[REQ-3-LAS-0240] The Laser System shall be designed to withstand operational basis survival conditions when there is no power to the observatory.

Discussion: The operational basis survival conditions are defined in [REQ-3-LAS-0230].

[REQ-3-LAS-0250] The Laser System shall be designed such that loss of power will not cause damage to the Laser System, to the LGSF or to the observatory, whatever the operating state of the Laser System when the loss of power event occurs.

Discussion: Note that the Laser System will not be attached to an uninterruptible power system (UPS). See section 3.6.1, Services and utilities interface.

[REQ-3-LAS-0260] The Laser System shall withstand peak accelerations << 1.5 g (TBC) due to the 10-year return period earthquake conditions, with no damage or necessary re-alignments to the Laser System. Inspection of the Laser System before returning to normal operations shall be sufficient (as stated in Table 1).

[REQ-3-LAS-0270] The Laser System shall withstand peak accelerations < 1.5 g (TBC) due to the 200-year return period earthquake conditions, with no damage or necessary re-alignments to the Laser System. Inspection of the Laser System before returning to normal operations shall be sufficient (as stated in Table 1).

[REQ-3-LAS-0280] The Laser System shall be able to survive a 1.5 g (TBC) peak acceleration due to the 1000-year return period earthquake conditions, in any direction, without damage to the Laser System, or any other telescope sub-systems, but allowing re-alignments of the Laser System (as stated in Table 1).

[REQ-3-LAS-0290] After an earthquake, the time to inspect and re-align the Laser System components shall be as described in Table 1:

	Time to inspect	**Time to repair**
10-year return period earthquake	No longer than 6 hours	N/A
200-year return period earthquake	No longer than 6 hours	N/A
1000-year return period earthquake	No longer than 6 hours	Within 7 days

Table 1: Laser System time to inspect and repair after an earthquake

3.3 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

3.3.1 Laser Power Requirements

[REQ-3-LAS-0300] The Laser System implemented at TMT first light shall produce a total of at least 150W of ~589 nm light in either Continuous Wave (CW) or mode locked CW pulse format, generated by one of the following technologies:

- Sum Frequency Generation (SFG) using 1319nm and 1064nm solid state lasers.
- Frequency doubled Second-Harmonic Generation (SHG) conversion from a 1178nm laser.

Discussion: The NFIRAOS asterism consists of six 25W LGS, therefore a total of at least 150W is required to produce the NFIRAOS asterism.

The Laser System implemented at TMT first light will be referenced as "the first light Laser System" in the rest of the document.

[REQ-3-LAS-0310] The first light Laser System shall implement six plus one spare (seven total) 25W Laser Units of the type defined in [REQ-3-LAS-0300].

Discussion: The NFIRAOS asterism includes six 25W LGS. A spare laser is added for redundancy. Also note that laser power is specified at the output of the Laser Head (i.e. after the output aperture of the Laser Head).

[REQ-3-LAS-0320] Each individual Laser Head shall provide a coupling efficiency of at least 130 photons-m^2/s/W/ion (TBC) with the mesospheric sodium layer, over a period of at least 12 hours. The coupling efficiency is based on the following parameters: a LGS beam diameter at the altitude of the sodium layer of ~0.2m (TBC), a nominal sodium column density of 4x10^{13} ions/m^2, and an angle of 21 degrees (Armazones) or 40 degrees (Mauna Kea) (TBC) between the direction of the laser propagation and the Earth's magnetic field.

Discussion: The total power level and coupling efficiency yield the required photon return at the LGS wavefront sensor (WFS) for the estimated optical throughput and sodium layer parameters.

Note also that 25W per beacon at this coupling efficiency is required to satisfy the first light NFIRAOS wavefront error budget at all times, including those times with lower than average sodium column density. At a minimum, a reduced power level of 17W per beacon provides acceptable performance at a sodium column density of 3x10^{13} ions/m^2, and satisfies the first light NFIRAOS wavefront error budget during times with median or higher sodium column density.

[REQ-3-LAS-0330] The Laser System shall be upgradeable to eight plus one spare (nine total) 25W Laser Units of the type defined in [REQ-3-LAS-0300].

Discussion: The upgraded Laser System will be referenced as the final Laser System in the rest of the document.

[REQ-3-LAS-0340] The short-term (defined as a RMS variability over a 5–minutes period) power stability of each Laser Unit shall be 3% or better.

[REQ-3-LAS-0350] The long-term (defined as a peak to peak variation over a 12–hours period) power stability of each Laser Unit shall be 15% with a goal of 10%.

3.3.2 Laser Beam Performance Requirements

[REQ-3-LAS-0400] Ninety five per cent of the transmitted (far-field) laser beam energy for each individual Laser Unit shall be contained in a 1.1 times diffraction-limited core, with a **goal** of 1.01.

Discussion: Note that the beam performance requirement is defined at the output of the Laser Head (i.e. after the output aperture of the Laser Head).

[REQ-3-LAS-0410] The laser output beams of each individual Laser Unit shall be 98% linearly polarized.

Discussion: Specifications regarding the polarization direction will be defined in the next version of the document.

[REQ-3-LAS-0420] The output beam diameter in the plane of each Laser Head output aperture shall be 5mm ±0.3mm (TBC) at the 1/e^2 intensity points.

Discussion: Specifications regarding the angular divergence of the output beams will be defined in the next version of the document.

[REQ-3-LAS-0430] The output laser beam position stability of each Laser Unit shall be as follows:

- Bias pointing accuracy between high and low power beams: ≤ 25 μrad (TBC) (Peak to peak variation),
- Pointing jitter: ≤ 3 μrad RMS (TBC),
- Long term drift: ≤ 100 μrad (TBC) (Peak to peak variation defined over a 12-hours period),

- Lateral shift: ≤ 0.5 mm (TBC) (Peak to peak variation).

Discussion: See [REQ-3-LAS-0510] and [REQ-3-LAS-0511] for low power beam requirements. The pointing jitter requirement of 3 μrad corresponds to 1/20 μrad on the sky, which is about 10 milliarcsec.

[REQ-3-LAS-0440] Each Laser Unit shall include internal sensors to monitor laser power, wavelength, polarization state and beam quality.

Discussion: Far field beam quality is measured in % of closed energy in a diffraction-limited core.

[REQ-3-LAS-0441] In the case of mode locked CW pulse format lasers, each Laser Unit shall also include internal sensors to monitor line width and temporal pulse format.

3.3.3 Laser Operation Requirements

[REQ-3-LAS-0500] Each Laser Unit shall include a laser shutter, capable of absorbing the full laser power indefinitely.

Discussion: There shall be no additional heat load presented to the ambient environment when the laser shutter is closed

[REQ-3-LAS-0510] Each Laser Unit shall provide a low power beam of 50 milliwatts average power to be used for internal LGSF alignment and diagnostics.

Discussion: The low power beam can be generated with (1) the high power laser operated in a low power mode, (2) an internal alignment laser or (3) an external laser.

[REQ-3-LAS-0511] The pointing accuracy of the low power beam shall be less than 100 μrad (TBC).

[REQ-3-LAS-0520] The Laser System shall provide a means to tune on and off the sodium D_2 line with a frequency shift of 10 GHz and a power stability of 3%.

[REQ-3-LAS-0521] The time to tune on or off the sodium D_2 line shall be less than 1 second with a **goal** of 100 milliseconds.

Discussion: This feature will be used to measure the strength of Rayleigh backscatter during a LGS WFS calibration, which will be performed for each science observation during a TMT night (could be as often as every 5 minutes).

[REQ-3-LAS-0530] The Laser System shall at least include the following operation modes:

- Off mode: The Laser System is powered down.
- Shuttered mode: The Laser System is powered on and ready for use but the output beams are shuttered with the laser shutters. The low power option can be either on or off.
- Run mode: The Laser System is powered on and the output beams are propagated through the LGSF Beam Transfer Optics. The low power option can be either on or off. The wavelength shift can be either on or off.

Discussion: Additional operation modes may be defined by the Laser Manufacturer (i.e. intermediate states).

[REQ-3-LAS-0540] The Laser System shall start up automatically from a cold start (off-mode) to the shuttered mode in no longer than 30 minutes.

[REQ-3-LAS-0550] The Laser System shall shutdown automatically from the shuttered mode in no longer than 30 minutes.

[REQ-3-LAS-0560] The Laser System shall implement an emergency shutdown, which shall shutdown the Laser System in less than 0.1 second (TBC) while minimizing the damage to the Laser Heads.

[REQ-3-LAS-0570] The Laser System shall be able to propagate the laser beams (Run mode) in less than 2 seconds from the shuttered mode.

Discussion: The time to open the shutter shall be compliant with current Laser Safety regulations.

[REQ-3-LAS-0580] The laser shutters shall close in 1 second or less.

[REQ-3-LAS-0590] The laser shutters shall be designed to close automatically in the event of a power failure.

[REQ-3-LAS-0600] Options shall be provided to control the laser shutters both manually via hardware and remotely via software.

3.3.4 Laser System Location and Mass Requirements

[REQ-3-LAS-0700] The Laser System shall be located within the ($-X_{ACRS}$, $-Y_{ACRS}$) quadrant of the telescope azimuth structure.

Discussion: This means that the Laser System will be operated in a fixed gravity vector.

[REQ-3-LAS-0710] The Laser System shall be able to operate with a maximum telescope angular acceleration around azimuth of 0.2 deg/s^2.

[REQ-3-LAS-0720] The Laser System shall be able to operate with a maximum telescope angular velocity around azimuth of 2.5 deg/s.

[REQ-3-LAS-0730] The Laser System shall be able to operate without a dedicated clean room.

Discussion: Maintenance of the Laser Unit modules can be performed in a dedicated clean room at the observatory if necessary but this clean room is not mounted on the telescope structure.

[REQ-3-LAS-0740] The final Laser System mass shall not exceed 9 tonnes.

Discussion: This includes the 9 Laser Units, the Laser Sequencer and the optional Laser Cooling System.

[REQ-3-LAS-0750] The maximum volume and location of the final Laser System shall be as described in section 3.6.1.

[REQ-3-LAS-0760] The output laser beam location of each Laser Head of the final Laser System shall be as described in section 3.6.4.

3.3.5 Laser System Power Consumption, Dissipation and Cooling Requirements

[REQ-3-LAS-0800] The total power consumption of the final Laser System shall not exceed 48,000 Watts.

[REQ-3-LAS-0810] The total power dissipation into the surrounding air by the final Laser System shall not exceed 200 Watts (TBC).

[REQ-3-LAS-0820] The Laser System shall use the chilled liquid cooling system provided by the TMT Observatory. The TMT Observatory cooling system is described in Table 2:

	Type	Value
Coolant fluid	Chilled glycol/water mixture (Percentage glycol by volume 35% (TBC))	-
Supply temperatures available	-	- 5 °C below predicted night time low temperature (accuracy ± 1.5°C) and/or - Fixed temperatures -9 °C or +7 °C (accuracy ± 1.5 °C)
Minimum pressure to which the Laser System shall be tested	-	10 bar (TBC) (Typical system operating supply pressure is expected to be approximately 5 bar (TBC))
Max pressure drop	-	1 bar (TBC)

Table 2: TMT Observatory Cooling System provided to the Laser System

Discussion: If the TMT Observatory Cooling System does not meet the Laser System needs, an additional specialized Laser Cooling System may be provided by the Laser Manufacturer.

Note that compressed refrigerant (e.g. Hydrochlorofluorocarbon (HCFC)) and pressurized helium could also be made available (TBC) to the Laser Vendor if needed.

3.3.6 Laser System Emission Requirements

[REQ-3-LAS-0900] The Laser System shall not emit light into the enclosure.

Discussion: The Laser System shall be designed to prevent generation of stray light during operational conditions.

[REQ-3-LAS-0910] The Laser System shall be designed to ensure that it will not emit electromagnetic radiation at any frequency that will adversely interfere with other electronic systems of the observatory.

Discussion: This requirement will be detailed further.

3.3.7 Laser System Vibration Requirements

[REQ-3-LAS-0920] The vibrations coupled from the Laser System into the telescope structure shall be minimized.

Discussion: Particular attention shall be given to the Laser Cooling System, if such a system is needed. The use of pumps, and rotating equipment such as fans, motors or other sources of vibrations shall be limited. If necessary, the Laser Cooling System can be located remotely in an area where vibrations are less of an issue.

This requirement will be detailed further.

3.3.8 Laser System Software Requirements

Discussion: The Laser System software requirements are based upon the Laser System sub-system decomposition described in sections 2.6 and 3.1.2. Basically, the Laser System is composed of several identical Laser Units and one Laser Sequencer. Each Laser Unit consists of a Laser Controller and a Laser Head.

The Laser Sequencer synchronizes, controls and monitors the multiple Laser Units. It consists of a computer and software system. The Laser Sequencer acts as the principal *interface to the rest of the observatory software systems. The Laser Sequencer is expected to communicate with the other software observatory systems using the TMT common software and protocol, which are not yet defined.*

The choice of a communication protocol between the Laser Sequencer and the Laser Controllers is left to the Laser Vendor.

The following block diagram shows the interfaces between the Laser System components and the other observatory software systems.

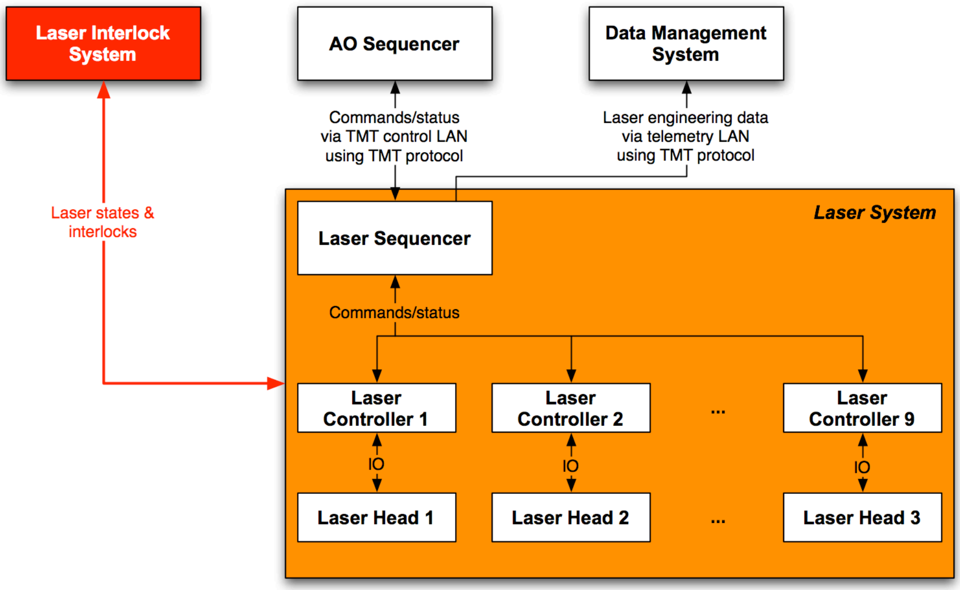

Figure 2: Laser System Control Block Diagram

The following sections give the software requirements for the Laser Controllers and the Laser Sequencer.

3.3.8.1 Laser Controller Requirements

[REQ-3-LAS-1000] Each Laser Controller shall implement an engineering UI.

[REQ-3-LAS-1010] Each Laser Controller shall support remote user interfaces.

[REQ-3-LAS-1020] It shall be also possible to operate each Laser Controller locally without the need of an external computer or terminal.

[REQ-3-LAS-1030] Each Laser Controller shall control and monitor the performance of its associated Laser Head.

[REQ-3-LAS-1040] At a minimum, each Laser Controller shall implement the commands listed in Table 3:

Configure a Laser Unit (initialize all parameters, including servo parameters if any)	[REQ-3-LAS-1042]
Full start-up sequence for a Laser Unit, implemented either as one automatic sequence or as a series of individual steps	[REQ-3-LAS-1044]
Full shutdown sequence for a Laser Unit, implemented either as one automatic sequence or as a series of individual steps	[REQ-3-LAS-1046]
Open and close the laser shutter	[REQ-3-LAS-1048]

Turn on and off the low power mode	[REQ-3-LAS-1050]
Shift the laser central frequency off and back onto the sodium D2 line	[REQ-3-LAS-1052]
Complete internal diagnostic test sequence for a Laser Unit, implemented either as one automatic sequence or as a series of individual steps	[REQ-3-LAS-1054]
Complete automated alignment sequence, for a Laser Unit, implemented either as one automatic sequence or as a series of individual steps	[REQ-3-LAS-1056]

Table 3: Laser Controller Functions

[REQ-3-LAS-1060] At a minimum, each Laser Controller shall be able to monitor/query the following Laser Unit parameters:

- Laser Unit status,
- Laser Unit power mode,
- Laser Unit frequency shift mode,
- Laser Unit internal faults and warnings,
- Laser Unit output power,
- Laser Unit wavelength and line width,
- Laser Unit temporal pulse format (for mode locked CW lasers),
- Laser Unit polarization state,
- Laser Unit beam quality,
- And all other appropriate sensor measurements such as temperatures, dew, currents within the Laser Unit…

[REQ-3-LAS-1070] Each Laser Controller shall boot or reboot from a cold start in less than 30 seconds and be initialized with a default configuration.

Discussion: At the end of the boot process, the Laser Controller shall connect to the Laser Sequencer, and display the status and health of its Laser Head.

The definition of the physical and software protocol to interface the Laser Controllers and the Laser Sequencer is the responsibility of the Laser Vendor.

[REQ-3-LAS-1080] It shall be possible to remotely reset/reboot each Laser Controller.

[REQ-3-LAS-1090] The Laser Controllers shall be operable as standalone systems without the need for interface to the Laser Sequencer.

[REQ-3-LAS-1100] Each Laser Controller shall gracefully recover from the interruption of the network without requiring a reset/reboot.

Discussion: In particular, the connection to the Laser Sequencer shall be automatically re-established.

[REQ-3-LAS-1110] The load of each Laser Controller's processing unit(s) shall not exceed 70%.

3.3.8.2 Laser Sequencer Requirements

[REQ-3-LAS-1200] The Laser Sequencer shall implement an engineering UI.

[REQ-3-LAS-1210] The Laser Sequencer shall support remote user interfaces.

[REQ-3-LAS-1220] The Laser Sequencer shall also be operable locally without the need of an external computer or terminal.

[REQ-3-LAS-1230] The Laser Sequencer shall control, synchronize and monitor the performance of the multiple Laser Units.

[REQ-3-LAS-1240] The Laser Sequencer shall be configurable to control any number of Laser Units up to 9.

[REQ-3-LAS-1250] At a minimum, the Laser Sequencer shall implement the commands listed in Table 4:

Configure all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1252]
Start all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1254]
Stop all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1256]
Open or close all laser shutters, any laser shutter individually, or any possible combination	[REQ-3-LAS-1258]
Turn on/off the low power mode of all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1260]
Shift off/back the central line frequency of all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1262]
Test all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1264]
Align all lasers, any laser individually, or any possible combination	[REQ-3-LAS-1266]

Table 4: Laser Sequencer Functions

Discussion: Some of these commands may be restricted to authorized personnel.

[REQ-3-LAS-1270] At a minimum, the Laser Sequencer shall be able to monitor/query the overall health and parameters of the Laser System:

- Laser Unit status,
- Laser Unit power mode,
- Laser Unit frequency shift mode,
- Laser Unit internal faults and warnings,
- Laser Unit output power,
- Laser Unit wavelength and line width,
- Laser Unit temporal pulse format (for mode locked CW lasers)
- Laser Unit polarization state,
- Laser Unit beam quality,
- And all other appropriate sensor measurements such as temperature, dew, current within the Laser Units…

[REQ-3-LAS-1280] The Laser Sequencer shall interface with the AO Sequencer to receive commands and parameter messages and to return response, status or event messages as described in section 3.6.2.

[REQ-3-LAS-1290] The Laser Sequencer shall be available to accept or reject commands from the AO Sequencer at all times. The time to accept or reject a command shall be less than 0.1 seconds.

[REQ-3-LAS-1300] The Laser Sequencer shall implement a high-level simulation mode where the interface with the AO Sequencer is simulated.

Discussion: The simulation mode shall provide a method for the AO Sequencer to check command flow and sequencing. The commands from the AO Sequencer will be received by the Laser Sequencer, and be accepted or rejected but not executed.

[REQ-3-LAS-1310] The Laser Sequencer shall publish a heartbeat variable updated at a rate of 1Hz.

[REQ-3-LAS-1320] The Laser Sequencer shall interface with the Data Management System to transfer specific Laser System parameters at a maximum rate of 1 Hz or upon change as described in section 3.6.3.

[REQ-3-LAS-1330] The Laser Sequencer shall boot or reboot from a cold start in less than 30 seconds and be initialized with a default configuration.

Discussion: At the end of the boot process, the Laser Sequencer shall connect to all Laser Controllers, check the health and status of these systems and report the overall Laser System health and status to the AO Sequencer.

[REQ-3-LAS-1340] It shall be possible to remotely reset/reboot the Laser Sequencer.

[REQ-3-LAS-1350] The Laser Sequencer shall be able to operate as a standalone system and shall work without the need for interfaces to other TMT sub-systems.

[REQ-3-LAS-1360] The Laser Sequencer shall gracefully recover from the interruption of the network without requiring a reset/reboot.

Discussion: In particular, the connections to the Laser Controllers and to the AO Sequencer shall be automatically re-established.

[REQ-3-LAS-1370] The load of each Laser Sequencer's processing unit(s) shall not exceed 70%.

3.4 SYSTEM ATTRIBUTES REQUIREMENTS

3.4.1 Reliability Requirements

[REQ-3-LAS-01400] The Laser System shall be able to operate and meet all requirements for 10 years given preventive and corrective maintenance.

Discussion: "Preventive and corrective maintenance" means servicing, repairing, and replacing components and sub-systems based on their expected lifetime, as opposed to their failure.

[REQ-3-LAS-1410] The unscheduled downtime for the Laser System shall not exceed 0.26% of the overall science time budget.

Discussion: This corresponds to ~8 hours of the 3000 hours of scheduled science observations per year.

[REQ-3-LAS-1420] The unscheduled downtime for the Laser Sequencer shall not exceed 0.01% of the overall science time budget.

Discussion: This corresponds to ~20 minutes of the 3000 hours of scheduled science observations per year.

[REQ-3-LAS-1430] For the final Laser System, the unscheduled individual Laser Unit downtime budget shall not exceed 0.85% of the overall science time budget.

Discussion: The downtime budget for an individual Laser Unit (p) can be computed via the following formula:

$$P_{LASER} = 1 - \sum_{i=N-1}^{N} \frac{N!}{i!(N-i)!}(1-p)^i p^{N-i}$$

where N is the total number of Laser Units (seven for the first light Laser System and nine for the final Laser System) and P_{LASER} *=0.0025 is the downtime budget corresponding to the complete Laser System.*

The Laser System is considered to have failed, if two or more Laser Units fail at any point during the night.

Finally, a downtime budget of 0.85% corresponds to ~26 hours of the 3000 hours of scheduled science observations per year.

[REQ-3-LAS-1440] The Laser Unit Mean Time Between Failure (MTBF) assuming preventive and corrective maintenance shall be at least ~1400 hours, with the Laser Units turned on 12 hours per 24 hours. A Laser Unit failure consists of one of the following conditions:

- The output on axis intensity of the Laser Unit is degraded by more than a factor of two as estimated from the ratio of the laser power and the beam quality measurement.
- The wavelength is shifted by more than ± 0.5 GHz
- The power stability is > 10% (defined as a RMS variability over a 5–minutes period).

3.4.2 Safety and Security Requirements

[REQ-3-LAS-1500] The Laser System shall comply with all the laser safety regulations to be described in the TMT Laser Safety Program Document.

Discussion: This document is not yet available. Please refer to section 2.5 for further discussions.

[REQ-3-LAS-1510] There shall be a start-up key lock switch located on each Laser Unit.

Discussion: It shall not be possible to turn on a Laser Unit unless the key lock is in the required position.

[REQ-3-LAS-1520] Each Laser Unit shall be enclosed in a housing, which prevents laser light emission except at the location of the output beam aperture.

[REQ-3-LAS-1530] The Laser Unit enclosure doors and covers shall be equipped with safety interlocks to prevent the Laser Units operation with an open door or cover.

[REQ-3-LAS-1540] The Laser System shall include all laser safety indicators and warning labels specified in the TMT Laser Safety Program Document. Indicator lights shall be visible through all required safety glasses.

Discussion: Indicator lights in the dome may not be allowed at night. Indicator sounds may be used instead, if necessary.

[REQ-3-LAS-1550] The Laser System shall implement internal safety features to automatically shutter the beams and/or perform an emergency system shutdown if required by a sub-system failure.

[REQ-3-LAS-1560] A failure of any of the Laser System computing system (software and hardware) shall not cause any damage to the Laser System.

[REQ-3-LAS-1570] The Laser System shall be designed to ensure that no fluids, particles or other materials (e.g., service panel fasteners) can drip or fall onto telescope subsystems or personnel below the laser system platform.

Discussion: This includes but is not limited to coolant and cleaning fluids.

3.4.3 Maintainability Requirements

[REQ-3-LAS-1600] The Laser System design shall be modular. Each sub-system of the Laser System shall be an assembly of small modules, each of which can be removed or replaced by a small team of TMT trained technicians, while the remaining modules remain mounted on the telescope.

[REQ-3-LAS-1610] Laser System maintenance requirements shall be minimized and limited as far as possible to preventive maintenance.

Discussion: Preventive maintenance includes but is not limited to:

- *Inspection;*
- *Checks of functional performance;*
- *Optical re-alignment;*
- *Cleaning optical surfaces;*
- *Component replacements before failure.*

[REQ-3-LAS-1620] At a minimum, all inspections, checks, and maintenance re-alignment of the Laser System shall be performed by a small team of TMT trained technicians, while the Laser System remains mounted on the telescope.

[REQ-3-LAS-1630] Other maintenance tasks shall be performed on-site in a dedicated Laser Clean Room, by a small team of TMT trained technicians, after removing a small module from the Laser System.

Discussion: A small, class 10,000 clean room will be available at the Observatory site for preventive maintenance and repair/corrective maintenance of the Laser System modules.

[REQ-3-LAS-1640] The processes of removing and replacing a Laser System module shall be repeatable and shall not degrade the performance of the Laser System.

[REQ-3-LAS-1650] The time required to perform Laser System maintenance tasks shall be as stated in Table 5:

Maintenance tasks	Time	Staff
Preventive maintenance tasks not requiring a module exchange	< 2 hours per day	One TMT trained technician
Other maintenance tasks requiring a module exchange	< 2 hours on the telescope azimuth structure < 4 hours in the dedicated clean room	Two TMT trained technicians

Table 5: Time to perform Laser System maintenance tasks

3.5 ACCESS AND HANDLING REQUIREMENTS

[REQ-3-LAS-1700] The Laser System shall be designed for installation/removal into/from the Telescope Azimuth Structure within 1 day, with a crew of 2 TMT technicians, a crane operator, and safety personnel.

Discussion: A 2 tonne crane will be available to install and remove the components of the Laser System.

The installation time does not include the time necessary to assemble and align the lasers. Similarly, the removal time does not include the time necessary to pack the lasers and associated electronics.

[REQ-3-LAS-1710] To allow rapid installation and removal of the Laser System, the Laser System should be designed so that the number of connections is minimized and the connectors are accessible and easy to mount and dismount.

3.6 INTERFACE REQUIREMENTS

3.6.1 Telescope Structure (STR) Interface

[REQ-3-LAS-1800] The Laser System shall have a structural and mechanical interface with the telescope azimuth structure to be described in the STR to LGSF ICD.

[REQ-3-LAS-1810] The Laser System shall have an access and handling interface with the telescope azimuth structure to be described in the STR to LGSF ICD.

[REQ-3-LAS-1820] The Laser System shall have services and utilities interface with the telescope azimuth structure to be described in the STR to LGSF ICD.

Discussion: The STR to LGSF ICD is not yet available. The anticipated interfaces between the telescope structure and the Laser System are summarized here:

- *Structural and mechanical interface:*
  The Laser System will be mounted on the ($-X_{ACRS}$, $-Y_{ACRS}$) quadrant of the telescope azimuth structure as shown in Figure 3. The allowable envelope of the Laser System is illustrated in section 4 (Appendix: Laser System Envelope Drawing). It is expected that the Laser System will be composed of several components mounted on a platform. Note that this platform is part of the telescope azimuth structure and not part of the Laser System. The space in the Laser System envelope is entirely dedicated to the Laser System envelope.

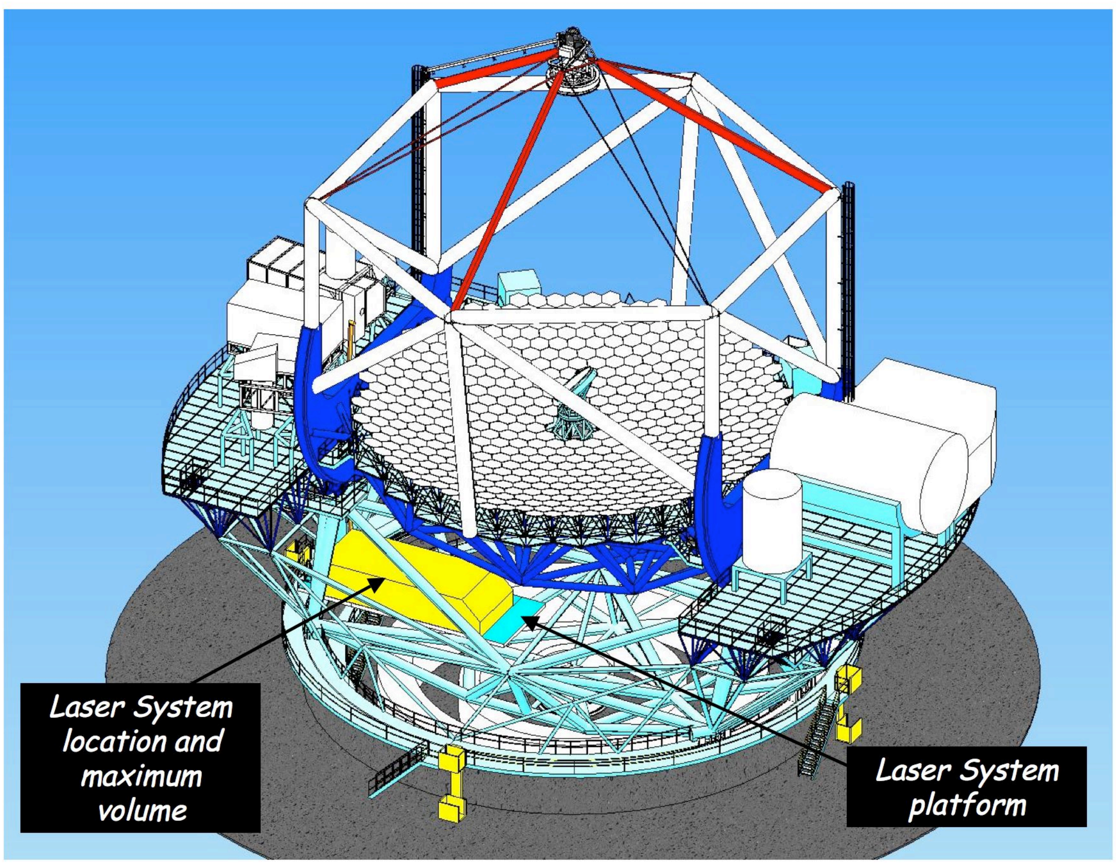

Figure 3: Laser System Location and Volume.

- *Access and handling interface:*

  A 2000kg overhead rail crane will be located above the Laser System envelope for installation and removal of the Laser System components. The crane location and reach is shown in the Laser System envelope drawing given in section 4. The Laser System platform will be accessible to personnel via stairs from the azimuth walkway.

- *Services and utilities interface:*

  i. *Both clean and dirty power will be distributed. Note that if necessary generator backup of either type of power or clean power that is connected to a central UPS system could be also available[2]. General utility power will be made available via industry standard keyed and color coded power outlets. Single and Three Phase power will be available; voltages and frequency characteristics are dependent on the site location (Mauna Kea: 480 Y 277 V @ 60Hz; Armazones: 400 Y 230 V @ 50Hz).*

  ii. *Copper wire and optical fiber will be available for control and communication (including but not limited to the network (control & telemetry LAN) and time-bus as shown in Figure 4).*

  iii. *Clean dry compressed air and coolant will be distributed.*

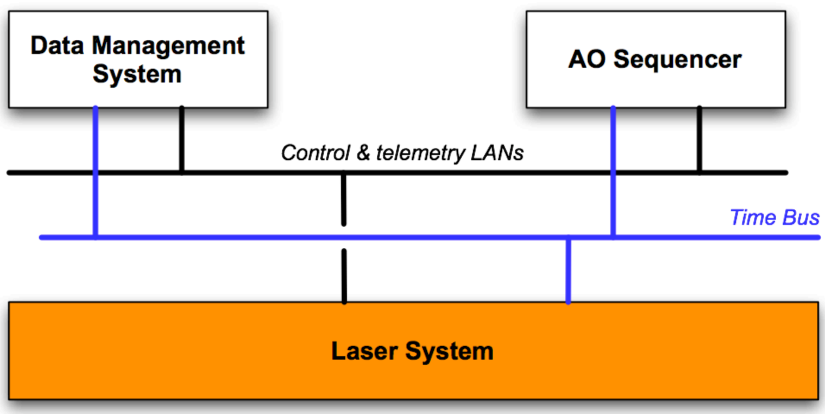

Figure 4: Laser System Control and Communication Interfaces

3.6.2 AO Executive Software (AOESW) Interface

[REQ-3-LAS-1900] The Laser Sequencer shall have a software and control interface with the AO Sequencer to be described in the LGSF to AOESW ICD.

Discussion: The AO Sequencer controls and synchronizes the actions of the different AO systems during science observations. The LGSF to AOESW ICD is not yet available. The interface between the Laser System and the AO Sequencer is summarized here:

- *The interface shall be implemented via Ethernet.*
- *The Laser System shall interface with the AO Sequencer to receive commands and parameters messages and to send back responses, status and event messages through a protocol to be defined by TMT. The protocol is not yet defined.*

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[2] Because of the cost of operations, the number of systems connected to generator backup or UPS will be limited.

- *At a minimum, the Laser System shall provide the following functions to the AO Sequencer:*
    - i. *Configure the Laser System*
    - ii. *Start/shutdown the Laser System ("start" may be restricted to authorized users)*
    - iii. *Open/close the laser shutters*
    - iv. *Turn on/off the low power mode of the Laser System*
    - v. *Shift off/back the central frequency of Laser System*
- *At a minimum, the AO Sequencer shall be able to monitor/query the following parameters:*
    - i. *Laser System status,*
    - ii. *Laser System power mode,*
    - iii. *Laser System frequency shift mode,*
    - iv. *Laser System faults, warnings, and interlocks,*
    - v. *Laser System laser parameters…*

3.6.3 Data Management System (DMS) Interface

[REQ-3-LAS-2000] The Laser Sequencer shall have a software and control interface with the Data Management System (DMS) to be described in the LGSF to DMS ICD.

Discussion: The Data Management System includes an engineering database. The purpose of this interface is to archive Laser System engineering data for maintenance purposes. The LGSF to DMS ICD is not yet available. The interface between the Laser System and the DMS is summarized here:

- *The interface shall be implemented via Ethernet.*
- *The Laser System shall interface with the Data Management System to transfer a set of defined Laser System parameters through a protocol to be defined by TMT, at a rate of 1Hz or upon change. The protocol is not yet defined.*
- *The Laser System shall provide the following time-stamped parameters to the Data Management System (note that the TMT time bus will be available to the Laser System):*
    - i. *Laser System status,*
    - ii. *Laser System power mode,*
    - iii. *Laser System frequency shift mode,*
    - iv. *Laser System faults, warnings, and interlocks,*
    - v. *Laser System laser parameters…*

3.6.4 LGSF Interface

[REQ-3-LAS-2100] The Laser System shall have a software and control interface with the LGSF Laser Interlock System to receive or generate interlock events to be described in the LGSF to LGSF LAS ICD.

Discussion: The LGSF to LGSF LAS ICD does not yet exist. The interlock interface between the Laser System and the Laser Interlock System (LIS) is summarized here:

This interface will be implemented via complementary TTL level signals (TBC). The signals must operate in a fail-safe mode so that if a signal line is broken the Laser System shall place its hardware in a safe state and/or the LIS shall raise the appropriate interlock to other systems.

The inputs to the LIS from the Laser System are (one interlock signal per Laser Unit):

- *Laser Units status (Off mode, Shuttered mode, Run mode),*
- *Laser shutters state (Open or closed),*
- *Laser Units faults (internal laser faults).*

The demands from the LIS to the Laser System are (one interlock signal per Laser Unit):

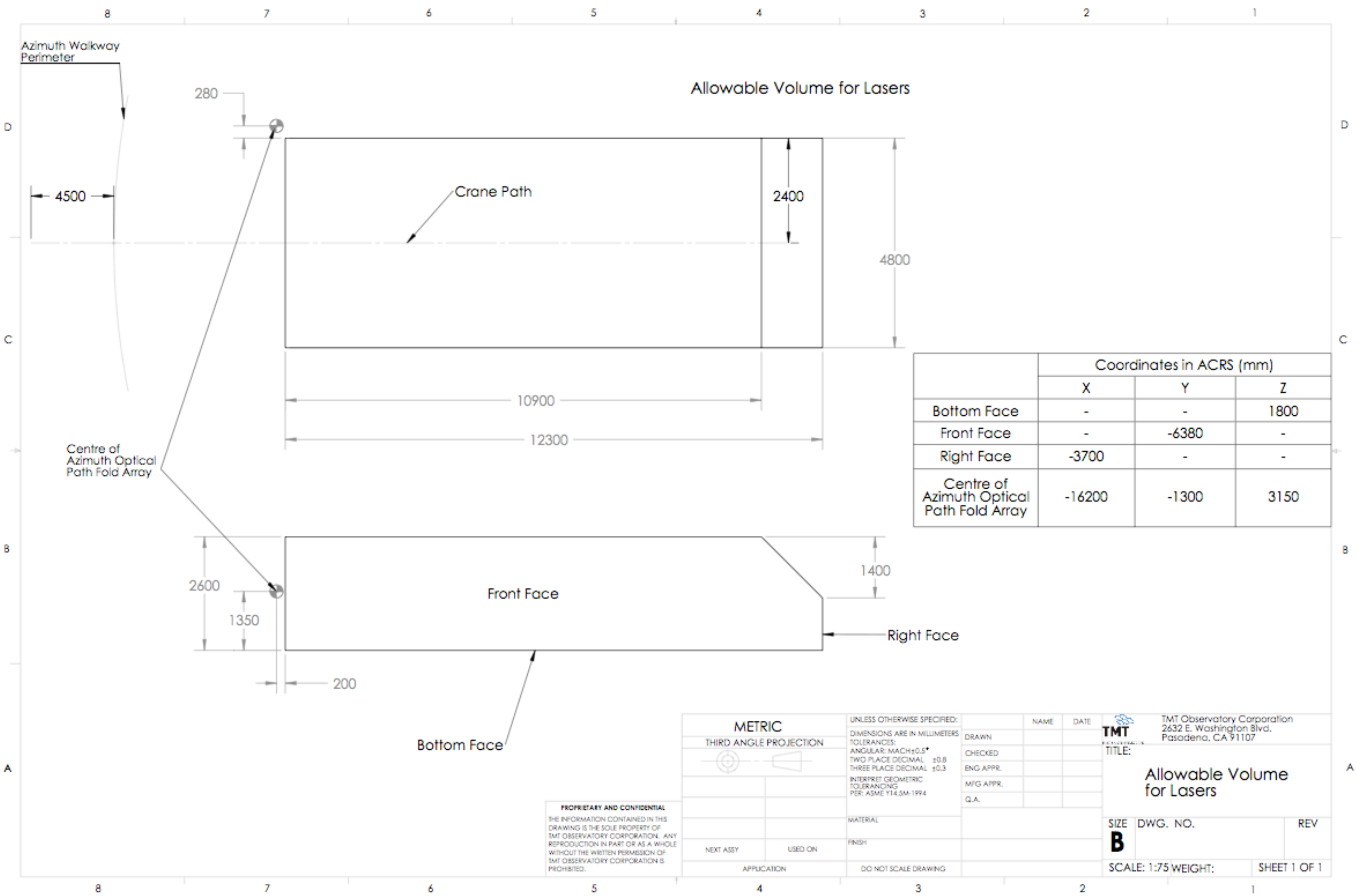
- *Close the laser shutter,*
- *Perform an emergency shutdown of the Laser Unit.*

[REQ-3-LAS-2110] The Laser System shall have a mechanical and structural interface with the Beam Transfer Optics and Laser Launch Telescope (BTO/LLT) System to be described in the LGSF to LGSF LAS ICD.

Discussion: The LGSF to LGSF LAS ICD is not yet available. The interface between the Laser System and the Beam Transfer Optics and Laser Launch Telescope (BTO/LLT) System is summarized here:

- *The Laser System is connected to the BTO Optical Path via a mechanical interface. The exact locations and alignment of the laser output beams at this interface are left to the Laser Vendor, but are constrained as follows:*
    i. *At the plane formed by the Azimuth Optical Path Fold Array shown in the Laser System Envelope Drawing in Appendix 4, the 9 beams of the final Laser System shall be parallel and form a 3x3 square pattern with a 140mm side (70mm between the centers of the beams).*
    ii. *For the first light Laser System, 7 of the 9 beams formed by the 3x3 square pattern will be populated.*
    iii. *Only one mirror per beam is allowed between the Laser System and the Azimuth Optical Path Fold Array (AZFA). Note that these Laser output mirrors and the AZFA are not part of the Laser System, but the placement and alignment of each output mirror may depend upon the Laser System layout.*

4. APPENDIX: LASER SYSTEM ENVELOPE DRAWING



	Coordinates in ACRS (mm)		
	X	Y	Z
Bottom Face	-	-	1800
Front Face	-	-6380	-
Right Face	-3700	-	-
Centre of Azimuth Optical Path Fold Array	-16200	-1300	3150