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Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project

ATLAS Laser Performance Specification

ICESat-2-ATSYS-SPEC-0099

Revision E

Effective Date: November 12, 2010

Released Version

Goddard Space Flight Center
Greenbelt. Marvland

National Aeronautics and
Space Administration

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In this document, a requirement is identified by “shall,” a good practice by “should,” permission by “may” or “can,” expectation by “will,” and descriptive material by “is.”

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CHANGE HISTORY LOG

Revision Level	DESCRIPTION OF CHANGE	Approved by	Date Approved
(-)	Baseline per ICESat-2 Score-0011	G. Jackson	11/24/2009
A	Released per ICESat-2 SCORE-0038	G. Jackson	06/07/2010
B	Released per ICESat-2 SCORE-0055	G. Jackson	07/27/2010
C	Released per ICESat-2 SCoRe-0064	G. Jackson	09/09/2010
D	Released per ICESat-2-SCoRe-0086	G. Jackson	11/02/2010
E	Released per ICESat-2-SCoRe-0109	G. Jackson	11/12/2010

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LIST OF TBDs/TBRs

Item No.	Location	Summary	Org/ Code	Due Date
TBR-1	*3.2*	*Pulse energy stable at commanded level within 10 min*	*554*	*3/2011*
TBR-2	*3.2*	*Pulse-to-pulse variation < 10% RMS…*	*554*	*3/2011*
TBR-3	*3.4*	*Pulse narrow and stable to transmit >85%...*	*554*	*3/2011*
TBR-4	*3.5*	*Optical power averaged over 500 ps….*	*554*	*3/2011*
TBR-5	*3.5*	*..time interval outside of the 5 ns…..*	*554*	*3/2011*
TBR-6	*3.5*	*…peak of the primary pulse shall be < 3%...*	*554*	*3/2011*
TBR-7	*3.5*	*…maximum optical power average over any 500 ps……*	*554*	*3/2011*
TBR-8	*3.10*	*…secondary modes shall have less than 10%....*	*554*	*3/2011*
TBR-12	*4.1*	*Electrical interface for commands and telemetry.*	*565*	*3/2011*
TBR-17	*3.17*	*Orientation during ATLAS thermal vacuum testing has not been finalized, may impact orientation requirement.*	545	3/2011
TBR-18	*4.8.1*	*..back reflections of <0.1% of the output optical signal*	551	3/2011
TBR-19	*4.8.2*	*..continue nominal operation after back-reflections of >0.1% and <5% of the output optical signal.*	551	3/2011

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1.0 General Information

1.1 Objective

This document captures the specification for a laser for the ATLAS instrument on ICESat-2. The laser is expected to be a pulsed infrared laser that is frequency-doubled to the visible spectrum.

1.2 Purpose

This specification describes the electrical, mechanical, operating environment, and verification testing requirements for a space-qualified, pulsed green laser component for a Goddard Space Flight Center (GSFC) Instrument, Advanced Topography Laser Altimeter System (ATLAS), primary instrument for the Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project.

1.3 ATLAS & Laser Transmitter Description

ATLAS is a multiple-beam laser altimeter. It illuminates 6 spots on the ground simultaneously with light from a single laser pulse. A fraction of the incident laser photons that are scattered by the earth surface and atmosphere are collected by the ATLAS receiver, along with “background” photons from sunlight, also scattered by the earth. The collected photons are detected by photon-counting detectors, resulting in records of photon detections associated with each illuminated spot, time-tagged with a precision of approximately 200 ps.

The Laser Transmitter Subsystem is envisioned as a self-contained unit in which nominally 28 V spacecraft power goes in and light pulses come out. The unit includes all electronics, optics, pump diodes, mechanical mounting, necessary diagnostics to monitor health and performance of the laser, necessary internal thermal control and any failsafe/protection systems required. The laser will be expected to be controlled from the ground, to change energy settings, maintain wavelength and maintain all performance parameters. The proper diagnostics and controls will need to be included.

The laser will operate at 10 kHz and will fire from a synchronization signal provided externally by the instrument.

The laser transmitter will have an electrical interface to receive power, thermal interface to remove heat, a mechanical interface to the instrument optical bench, and a communication interface for monitoring and controlling operational parameters.

All coordinates referenced in this document pertain to the local laser transmitter coordinate system as defined in this document.

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2.0 Documentation

2.1 Applicable Documents

The following documents and drawings in effect on the day this specification was signed shall apply to the fabrication and to the electrical, mechanical, and environmental requirements of the Laser Transmitter Subsystem to the extent specified herein. In the event of conflict between this specification and any referenced document, this specification will govern, with the exception of the Statement of Work, ICESat-2-LAS-CTR-0451, in which case the SOW takes precedence.

The following is a list of the applicable specifications and publications.

ICESat-2-ATSYS-REQ-0517, “ATLAS Component Environmental Requirements”

ICESat-2-SMA-REQ-0037, “Radiation Requirements Document (RRD)”

ICESat-2-ELEC-REQ-0189, “ATLAS Electrical Systems Requirements”

ICESat-2-ELEC-TN-0211, “ICESat-2 Figures to Accompany Electrical Systems Requirements”

ICESat-2-THM-IFACE-0214 “ATLAS Thermal ICD”

ICESat-2-SMA-ANYS-0125 “Radiation Environment Description Document”

ICESat-2-ATSYS-PLAN-0297, “ATLAS Contamination Control Plan”

2.2 Reference Documents

None

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3.0 Performance Requirements

3.1 Wall-Plug Efficiency

Wall-plug efficiency (WPE) is defined as the average output optical power (the product of pulse energy and repetition rate) from the laser transmitter divided by the electrical power draw from the instrument.

Requirement 3.1.1 At all energies less than 750µJ, the laser transmitter **shall** [3.1.1a] draw less than 150 W of electrical power at the beginning of life (BOL), and less than 177 W of electrical power at the end of life (EOL). The degradation rate **shall** [3.1.1b] not exceed 9 W/year.

Requirement 3.1.2 At pulse energies between 750µJ and 900 mJ, the wall-plug efficiency **shall** [3.1.2a] be greater than 5% at the BOL, and greater than 4.25% at EOL. The efficiency degradation rate **shall** [3.1.2b] not exceed 0.25 %/year.

3.2 Pulse Energy

Requirement 3.2.1 The laser transmitter output pulse energy **shall** [3.2.1] be adjustable by ground command from 250 microjoules to 900 microjoules in at least 32 evenly spaced steps.

Requirement 3.2.2 The laser transmitter output pulse energy **shall** [3.2.2] be stable (meaning it meets all performance requirements after transition period) at a commanded level within 10 minutes *[TBR-1]* after receiving a command.

Requirement 3.2.3 The pulse-to-pulse variation of pulse energy **shall** [3.2.3] be less than 10% RMS *[TBR-2]* over 1 second.

3.3 Center Wavelength

Requirement 3.3.1 The center wavelength **shall** [3.3.1] be 532 ±1 nanometers.

Requirement 3.3.2 The center wavelength of all flight laser deliverables **shall** [3.3.2] be within a 30 pm band.

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3.4 Wavelength Stability and Linewidth

Requirement 3.4.1 The laser transmitter spectrum **shall** [3.4.1] be narrow and stable enough to transmit >85% *[TBR-3]* (of the peak transmission of the filter) of the average pulse energy through a 30 picometer (FWHM) fixed etalon filter in the wavelength window 532±1 nm over any 1 millisecond time period.

3.5 Afterpulsing

Requirement 3.5.1 The optical power, averaged over any 500 ps *[TBR-4]* time interval outside of the 5 ns *[TBR-5]* time interval centered on the peak of the primary pulse, **shall** [3.5.1] be less than 3% *[TBR-6]* of the maximum optical power averaged over the 500 ps *[TBR-7]* time interval centered on the peak of the primary pulse.

3.6 Pulse Width

Requirement 3.6.1 The mean pulse width **shall** [3.6.1] be less than 1.5 ns FWHM.

3.7 Repetition Rate

Requirement 3.7.1 The pulse repetition rate **shall** [3.7.1] be 10 kHz ± 0.3 kHz.

Requirement 3.7.2 The laser transmitter pulse **shall** [3.7.2] be externally triggered from an instrument synchronization pulse.

Requirement 3.7.3 The maximum delay between a synchronization pulse and the laser pulse **shall** [3.7.3] not exceed 6 microseconds in more than one out of 10^4 pulses.

3.8 Polarization

Requirement 3.8.1 The output **shall** [3.8.1] be linearly polarized, with extinction ratio greater than 100:1.

3.9 Beam Diameter

Requirement 3.9.1 The beam exiting the laser (near-field) **shall** [3.9.1] be contained within a 15 mm (diameter) circular clear aperture.

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3.10 Spatial Mode

Requirement 3.10.1 A minimum of eighty-six percent (86%) of the pulse energy **shall** [3.10.1] be contained within a circular far field spot – defined to be 1.6 times the diffraction-limit of a 10 mm diameter circular Gaussian beam.

- *Example:* A 532nm, 10-mm circular laser beam focused with a 1-meter focal length lens has a diffraction limited $1/e^2$ diameter at the focus of 68 µm. We require 86% of the energy to be encircled by a diameter of <= 108 µm (= 68 µm * 1.6). (*Reference*: This corresponds to a near field divergence of 108 µrads.)

Requirement 3.10.2 The far field pattern **shall** [3.10.2a] have a primary single mode. Any secondary modes **shall** [3.10.2b] have less than 10% *[TBR-8]* of the total energy in the primary mode.

Requirement 3.10.3 The laser mode **shall** [3.10.3] meet these requirements on >99% of all shots in any 2 minute period of laser operation.

3.11 Beam pointing

Requirement 3.11.1 Beam **shall** [3.11.1] be directed perpendicular to the X-Y plane in the +Z direction as shown in Figure 2, with the external Risleys discussed below in a neutral (non-deflecting) position.

3.12 Pointing Stability

3.12.1 Shot-to-shot Pointing Stability

Requirement 3.12.1 The standard deviation of pointing direction of the beam exiting the laser, measured over any 10 millisecond time interval, **shall** [3.12.1a] be less than 10.8 µrad. Pointing direction **shall** [3.12.1b] be measured with respect to a reference on the instrument optical bench or test bench.

3.12.2 Short-term Pointing Stability

Requirement 3.12.2 The envelope of pointing direction of the beam exiting the laser transmitter enclosure, measured over the operating temperature range, **shall** [3.12.2a] be less than 21.6 µrad (RMS) for times less than 1 second. Pointing direction **shall** [3.12.2b] be measured with respect to a reference on the instrument optical bench or test bench.

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3.12.3 Mission-long Pointing Stability

Requirement 3.12.3 The envelope of pointing direction of the beam exiting the laser transmitter enclosure, measured over the operating temperature range, **shall** [3.12.3a] be less than +/-100 µrad (RMS). Pointing direction **shall** [3.12.3b] be measured with respect to a reference on the instrument optical bench or test bench. The laser pointing stability requirement **shall** [3.12.3c] be met during the entire mission so vacuum (causing changes in the index of refraction of laser's ambient atmosphere), launch loads, and all environmental factors need to be accounted for in the design.

3.13 External optics mount

Requirement 3.13.1 Attached to the outside of the laser transmitter enclosure **shall** [3.13.1] be a mounting fixture with a pair of Risley prisms for beam alignment to the rest of the instrument and a means to rotate the polarization 90 degrees.

Requirement 3.13.2 The externally mounted Risleys **shall** [3.13.2a] have a ± 2 mrad pointing range and **shall** [3.13.2b] be able to point anywhere within the ±2 mrad cone, with keyhole cone < 25urad (5arcsec) full-angle. Additionally, the external Risleys **shall** [3.13.2c] incorporate a locking feature or device such that after final alignment to the instrument optical bench they can be locked in-place for flight.

Requirement 3.13.3 The external optics mount **shall** [3.13.3a] accommodate a ½-wave-plate or quartz rotator for polarization rotation. If a polarization rotator is used, the linearly polarized light **shall** [3.13.3b] be oriented to within 1 degree of the x- or y-axis. (There is no orientation specification if a ½ waveplate is used because arbitrary orientations can be achieved by appropriate orientations of the waveplate.)

Requirement 3.13.4 Each externally mounted optic **shall** [3.13.4] be independently removable.

3.14 Interlock Switch

Requirement 3.14.1 The laser transmitter **shall** [3.14.1] incorporate a Safe/Arm connector (Safe – open connection, Armed – shorted) such that the transmitter light emission can be disabled while the laser transmitter remains powered and providing telemetry.

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3.15 Internal fail-safe switch

Requirement 3.15.1 The laser **shall** [3.15.1a] internally monitor its own health (for example, temperature, diode pump powers, optical energies) and cease all transmitter light emission but continue processing commands and telemetry when necessary to avoid damage. The internal monitoring **shall** [3.15.1b] have appropriate error messages to alert the user to the cause of the anomaly.

3.16 Lifetime

Requirement 3.16.1 The laser **shall** [3.16.1a] continuously operate on-orbit for a total of 3 years plus 60 days meeting all other specifications. This lifetime **shall** [3.16.1b] be met with a probability of success of 85% or greater.

Requirement 3.16.2 After delivery to GSFC, the laser transmitter **shall** [3.16.2] meet all specifications at the completion of acceptance testing and mission I&T lasting 6 months, operating continuously.

Requirement 3.16.3 After delivery to GSFC, the laser transmitter **shall** [3.16.3] meet all specifications at the completion of any ground storage phase. The ground storage phase will be two years.

3.17 Environment

Requirement 3.17.1 The laser transmitter **shall** [3.17.1] operate in a 1-G environment in 3 orientations: gravity vector in -X, -Y, and +Y axes *[TBR-17],* per Figure 1.

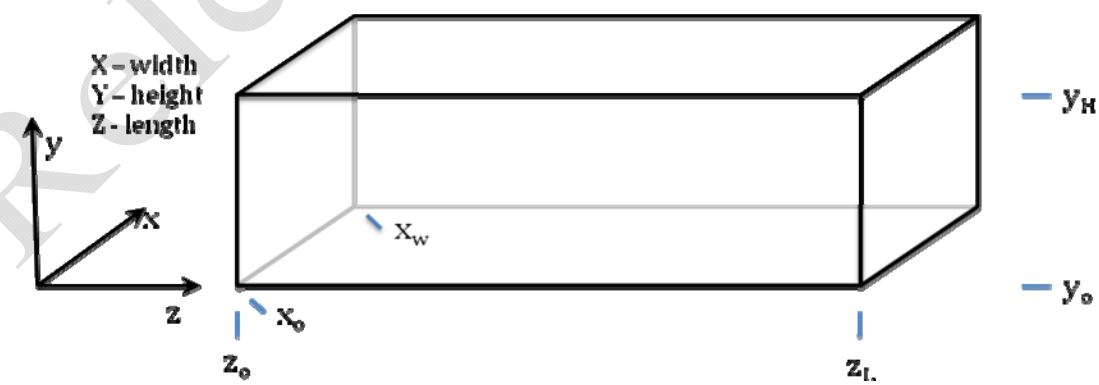

Figure 1 Envelope & Coordinate System of Laser Enclosure

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4.0 Interfaces

4.1 Electrical

Requirement 4.1.2 The electrical interface for commands and telemetry interface **shall** [4.1.2] be: Asynchronous serial (UART) protocol (example 9600 baud, 8 bits, odd/even parity) transmitted over half-duplex RS-422 Differential lines. *[TBR-12]*

4.2 Control and Telemetry

Requirement 4.2.1 The laser transmitter **shall** [4.2.1] telemeter all stage temperatures, currents, voltages, and optical power. The transmitter telemetry is not limited to these points.

Requirement 4.2.2 The laser transmitter **shall** [4.2.2] accept commands for power up, pulsing enable/disable, energy setpoint, and power down. The transmitter commanding is not limited to these modes.

4.3 Mechanical

4.3.1 Enclosure

The laser optics, including the cavity and doubling module, may be inside a hermetic enclosure with a suitable atmosphere inside.

Requirement 4.3.1 The laser optics, including the cavity and doubling module, **shall** [4.3.1] be inside a metallic enclosure housing.

4.3.2 Mass

Requirement 4.3.2 The total mass of the laser transmitter unit, including optics, doubling module, electronics, enclosure and outer beam steering optics (Risley/polarization management optics) **shall** [4.3.2] be less than or equal to 20 kilograms.

4.3.3 Center of Gravity

Requirement 4.3.3 The center of gravity location **shall** [4.3.3] be provided with respect to the mounting interface reference origin to +/-0.15 cm accuracy.

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4.3.4 Maximum Physical Envelope

Requirement 4.3.4 The laser transmitter **shall** [4.3.4] use the coordinate system shown in figure 1. This will be applicable for all analyses, drawings, and models.

Requirement 4.3.5 The maximum volume **shall** [4.3.5] be ≤ 50 cm length (Z axis), 30 cm width (X axis), 15 cm height (Y axis). Coordinate system with respect to Figure 1.

This volume includes optics, doubling module, electronics, and enclosure ports (if applicable), and connectors. This volume does not include the mounting components, external volume for beam steering optics (Risley/Beam Expander), optical alignment cube(s), or thermal heat pipe interface.

Requirement 4.3.6 The external volume for steering optics **shall** [4.3.6] be ≤4 cm length (Z axis), 4 cm width (X axis), 4 cm height (Y axis) as shown in Figure 2.

Requirement 4.3.7 The external volume for the thermal interface **shall** [4.3.7] be detailed within the vendor supplied mechanical ICD.

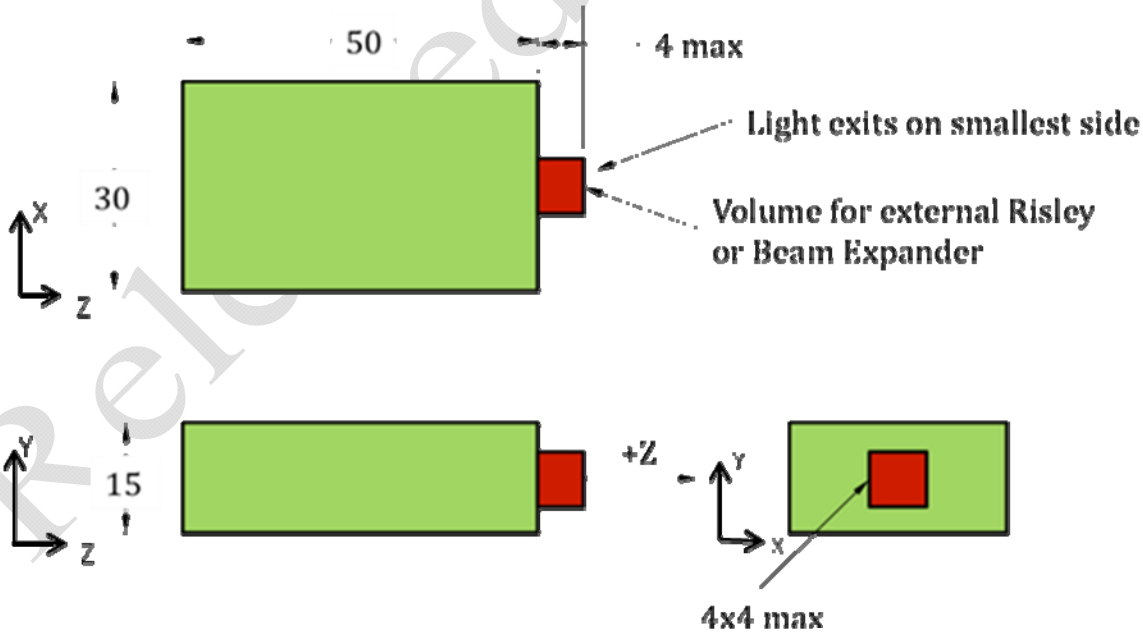

Figure 2 Laser Envelope with Light Exit Path (dimensions in cm)

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4.4 Optical Bench Mount

Requirement 4.4.1 The laser transmitter enclosure **shall** [4.4.1] limit the heat transfer to/from the instrument optical bench to no more than 0.15 W/C total, with the instrument optical bench in the temperature range of 0C to 40C.

Requirement 4.4.2 The mounting locations to the optical bench, **shall** [4.4.2] be contained within the planar view (X-Z plane) of the transmitter enclosure. The optical bench mounting components from the transmitter to the optical bench are not included in the volumetric requirement BUT are the responsibility of the Laser Vendor to design. Mass allocation provided in 4.3.2 is to include all optical bench mounting components.

4.5 Beam Alignment

Requirement 4.5.1 The exit beam centerline **shall** [4.5.1] be parallel to the best-fit plane containing all mounting feet to within ±1 mrad.

Requirement 4.5.2 The exit beam centerline **shall** [4.5.2] be offset no more than 7.5 cm from the bottom surface (-Y dir) of the laser enclosure (X-Z plane) (Figure 3).

Requirement 4.5.3 The vendor **shall** [4.5.3] measure the beam pointing angle relative to the optical alignment reference cube (section 4.8.2) to ± 0.1mrad.

Requirement 4.5.4 The best-fit plane containing all mounting feet **shall** [4.5.4] be no more than 7.5 cm below (-Y dir) the bottom surface of the laser enclosure (X-Z plane).

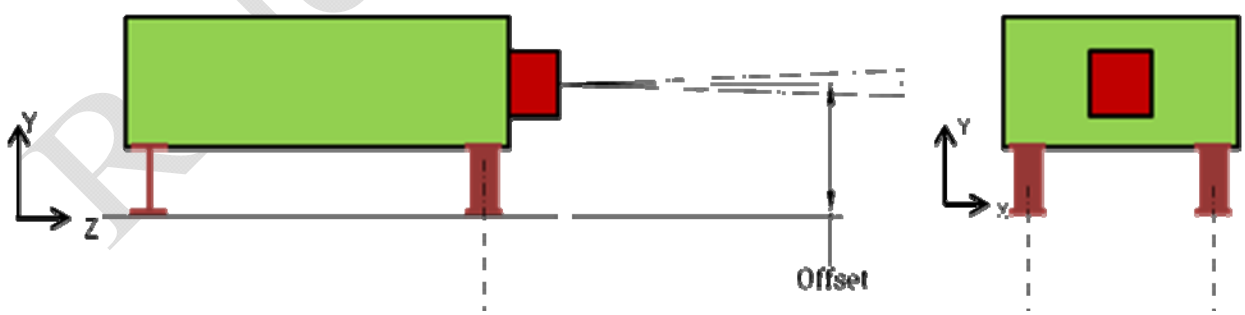

Figure 3 Exit Beam Alignment

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4.6 Electrical Connectors

Requirement 4.6.1 All electrical harnessing **shall** [4.6.1] exit though connectors located at the rear panel (parallel to the X-Y plane at Z_0, opposite the light exit side) of the housing within an area outside of the keep-out zone shown in figure 4.

4.7 Thermal

4.7.1 Conductive Thermal Interface

Requirement 4.7.1 The laser transmitter enclosure **shall** [4.7.1a] dissipate all internally generated heat through the conductive thermal interface which incorporates two identical mechanical interfaces. (NOTE: One of the mechanical interfaces will be used for the flight thermal control system and one will be used for the ground cooling system.) The interface location will be chosen by the laser vendor and **shall** [4.7.1b] be one of three options: parallel to the X-Z plane at $Y=Y_h$, parallel to the Y-Z plane at $X=X_w$ or $X=X_0$ (see figure 4).

Requirement 4.7.2 Each thermal interface will be 5cm wide and at least 30 cm long. This **shall** [4.7.2a] be a flat surface with 2 rows of bolts every 5 cm (figure 4). NOTE: Longer thermal interfaces are encouraged as it will increase the performance of the instrument thermal control system. When designing the mounting components (section 4.4) the laser vendor **shall** [4.7.2b] consider the mechanical loads induced by the heat pipes.

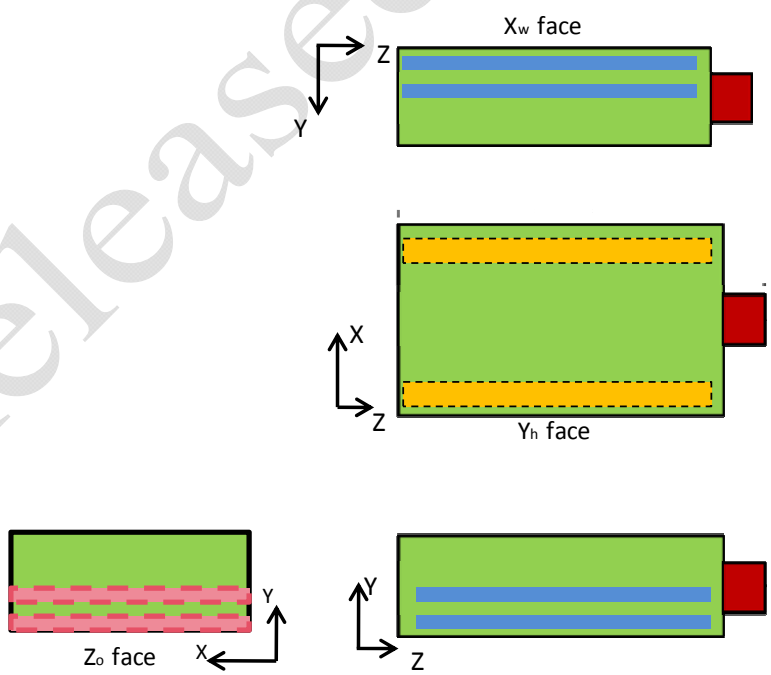

Figure 4 Thermal Interfaces

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Requirement 4.7.3 The maximum flux into the thermal interface **shall** [4.7.3] be less than 40 W per linear inch of heat pipe, assuming that the heat pipes run in the direction of the 30cm length of the thermal interface.

Requirement 4.7.4 If the thermal interface is chosen to be parallel to the Y-Z plane at $X=X_w$, then there **shall** [4.7.4a] be a corresponding 5cm high (measured from Y_0) stay-out zone on the plane parallel to the Y-X plane at either the $Z=Z_0$ or Z_L surfaces to allow for heat pipe routing. If the thermal interface is chosen to be parallel to the Y-Z plane at $X=X_0$, then the stay-out zone **shall** [4.7.4b] be on the Y-X plane at both $Z=Z_0$ and Z_L surfaces.

4.7.2 Radiative Thermal Interface

Requirement 4.7.5 Exterior areas of the laser transmitter housing will be covered with Multi-Layer Insulation (MLI). MLI **shall** [4.7.5] be GFE to laser vendor.

4.8 Optical

Requirement 4.8.1 Laser transmitter **shall** [4.8.1] continue nominal operation during back-reflections of <0.1% *[TBR-18]* of the output optical signal within a 0.1 mrad cone.

Requirement 4.8.2 Laser transmitter **shall** [4.8.2] continue nominal operation (i.e. incur no damage, though laser operation can be interrupted during the occurence) after back-reflections of ≥ 0.1% and <1% *[TBR-19]* of the output optical signal within a 0.5 mrad cone.

Requirement 4.8.3 The laser transmitter enclosure **shall** [4.8.3a] incorporate externally mounted alignment cube(s) visible from at least 3 orthogonal directions located adjacent to the laser exit point. Alignment cube **shall** [4.8.3b] be Jenoptik Ortholine 1” cube with pattern p/n ORC 1.0 or equivalent.

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APPENDIX A List of Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ATLAS	Advanced Topographic Laser Altimeter System
BOL	Beginning of Life
C	Centigrade
CBE	Current Best Estimate
CPS	Counts per Second
cm	centimeter
DOE	Diffractive Optical Element
EOL	End of Life
FWHM	Full width at half maximum
ICESat	Ice, Cloud, and Land Elevation Satellite
IR	Infrared
ITL	Integration & Test Laser
Kg	kilogram
kHz	kiloHertz
MAR	Mission Assurance Requirements
MCPS	MegaCounts per second
MICD	Mechanical Interface Control Drawing
mm	Millimeter
NIR	Near Infrared
nm	nanometer
ns	Nanosecond
O/E	Optical/Electrical
PAIP	Payload Assurance Implementation Plan
ps	Picosecond
RRD	Radiation Requirements Document
UART	Universal Asynchronous Receiver-Transmitter
V	Volts
W	Watt
WPE	Wall-Plug Efficiency

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APPENDIX B Integration & Test Laser Specification

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Integration & Test Laser (ITL) Specification			
Req ID	**Requirement Topic**	**Applicable to I&T-specific Laser (ITL)**	**ITL REQUIREMENT TAILORING**
Section 2.1	**Applicable Documents**		
ICESat-2-ATSYS-REQ-0517, "ATLAS Component Environmental Requirements"			
ICESat-2-SMA-REQ-0037, "Radiation Requirements Document (RRD)"			
ICESat-2-ELEC-REQ-0189, "ATLAS Electrical Systems Requirements"		X	The following are not applicable to ITL: ESR-14, 31, 39, 40, 99, 100, 112, 113, 117, 128, 131, and 132.
ICESat-2-ELEC-TN-0211, "ICESat-2 Figures to Accompany Electrical Systems Requirements"		X	
ICESat-2-THM-IFACE-0214 "ATLAS Thermal ICD"		1,2,3,4,5,6,9,17,18,19,20,21,95,96,23, 24,25,26,27,28,34,35,82,36,37,38,86, 39,40,41,57,58,59,78	
ICESat-2-SMA-ANYS-0125 "Radiation Environment Description Document"			
ICESat-2-ATSYS-PLAN-0297, "ATLAS Contamination Control Plan"		X	
Req ID			
3.1.1a	Wall-plug Efficiency	X	
3.1.1b	Wall-plug Efficiency		
3.1.2a	Wall-plug Efficiency	X	
3.1.2b	Wall-plug Efficiency		
3.2.1	Pulse Energy	X	
3.2.2	Pulse Energy	X	
3.2.3	Pulse Energy	X	
3.3.1	Center Wavelength	X	
3.3.2	Center Wavelength	X	The center wavelength shall be within a 30pm band of Serial No 1
3.4.1	Wavelength Stability and Linewidth	X	
3.5.1	Afterpulsing	X	
3.6.1	Pulse Width	X	
3.7.1	Repetition Rate	X	
3.7.2	Repetition Rate	X	
3.7.3	Repetition Rate	X	
3.8.1	Polarization	X	
3.9.1	Beam Diameter	X	
3.10.1	Spatial Mode	X	
3.10.2a	Spatial Mode	X	
3.10.2b	Spatial Mode	X	
3.10.3	Spatial Mode	X	
3.11.1	Beam Pointing	X	
3.12.1a	Shot-to-shot Pointing Stability	X	
3.12.1b	Shot-to-shot Pointing Stability	X	
3.12.2a	Short-term Pointing Stability	X	
3.12.2b	Short-term Pointing Stability	X	

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Integration & Test Laser (ITL) Specification (continued)			
Req ID	**Requirement Topic**	**Applicable to I&T-specific Laser (ITL)**	**ITL REQUIREMENT TAILORING**
3.12.3a	Mission-long Pointing Stability		
3.12.3b	Mission-long Pointing Stability		
3.12.3c	Mission-long Pointing Stability		
3.13.1	External Optics Mount	X	
3.13.2a	External Optics Mount	X	
3.13.2b	External Optics Mount	X	
3.13.2c	External Optics Mount		
3.13.3a	External Optics Mount	X	
3.13.3b	External Optics Mount	X	
3.13.4	External Optics Mount	X	
3.14.1	Interlock Switch	X	
3.15.1a	Internal fail-safe switch	X	
3.15.1b	Lifetime		
3.16.1a	Lifetime		
3.16.1b	Lifetime		
3.16.2	Lifetime	X	
3.16.3	Lifetime		
3.17.1	Environment	X	The ITL shall operate in any orientation in a 1-G environment
4.1.2	Electrical	X	
4.2.1	Control and Telemetry	X	
4.2.2	Control and Telemetry	X	
4.3.1	Mechanical Enclosure	X	
4.3.2	Mass		
4.3.3	Center of Gravity	X	
4.3.4	Maximum Physical Envelope	X	
4.3.5	Maximum Physical Envelope	X	
4.3.6	Maximum Physical Envelope	X	
4.3.7	Maximum Physical Envelope	X	
4.4.1	Optical Bench Mount		
4.4.2	Optical Bench Mount	X	
4.5.1	Beam Alignment	X	
4.5.2	Beam Alignment	X	
4.5.3	Beam Alignment	X	
4.5.4	Beam Alignment	X	
4.6.1	Electrical Connectors	X	
4.7.1a	Conductive Thermal Interface	X	
4.7.1b	Conductive Thermal Interface	X	
4.7.2a	Conductive Thermal Interface	X	
4.7.2b	Conductive Thermal Interface	X	
4.7.3	Conductive Thermal Interface	X	
4.7.4a	Conductive Thermal Interface	X	
4.7.4b	Conductive Thermal Interface	X	
4.7.5	Radiative Thermal Interface		
4.8.1	Optical	X	
4.8.2	Optical	X	
4.8.3a	Optical	X	
4.8.3b	Optical	X	

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