Laser Production for NASA's Global Ecosystem Dynamics Investigation (GEDI) Lidar

SPIE DSS April 19, 2016
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GEDI Mission Overview

- NASA Earth Ventures Instrument (EVI) program
- $90 M, cost capped, “PI-Led” mission
- Class C, 1-2 year mission
- Multi-beam waveform lidar instrument with 10 ground tracks
- Launch Vehicle: Space-X Falcon 9/Dragon or equivalent
- Platform: International Space Station,
- Japanese Experiment Module Exposed Facility, Site: EFU#6
- Orbit: 415 km average; 51.6 degrees
- Payload Allocations (TBR): 600 Kg., 887 W, 5.4 Mbps
- Science and Mission Operations Ground System, B.32 GSFC

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SRR</td>
<td>PDR</td>
<td>CDR</td>
<td>PER</td>
<td>PSR</td>
<td>LRD</td>
</tr>
<tr>
<td></td>
<td>6-15</td>
<td>4-16</td>
<td>1-17</td>
<td>8-17</td>
<td>5-18</td>
<td>8-18</td>
</tr>
</tbody>
</table>

Primary Mission: 365 Days of Science Collection
Extended Mission to Account for ISS Induced Downtime
Science Goal

Characterize the effects of changing climate and land use on ecosystem structure and dynamics

GEDI provides the Earth’s first comprehensive and high-resolution data set of ecosystem structure
Lidar Measurement

- Sole GEDI observable is the lidar waveform
  - Provide ground elevation, canopy height, canopy cover and various vertical profiles and metrics
• GEDI is self-contained laser altimeter

• 3 lasers produce a total of 10 ground tracks

• Precise ranging, attitude & position sensors enable precise geo-location of each laser footprint (10-m knowledge)

• Active Pointing Control Mechanism (PCM) provides even distribution and complete coverage of ground tracks (225-m control)
GEDI Instrument

- GPS Antenna
- Star Tracker #1
- Star Tracker #2
- Star Tracker #3
- FRGF
- PIU
- SpaceX Passive FSE x 4
- +Z_GEDI
- +Z_GEDI Fixtures
GEDI – Internal Views

- 3X Laser
- Star Tracker #2
- Star Tracker #3
- Star Tracker #1
- 3X TOA
- 3X BDU
- 4X Accumulator
- Pointing Control Mechanism
- Deployed Aperture Cover
- Sun Shade
GEDI Optical Bench

Star Tracker # 2

BDU #1

Laser # 1

TOA #3

BDU #3

Star Tracker # 3

Laser # 3

BDU #2

Star Tracker # 1

TOA #2

Laser # 2

RTA
17 mJ

HR = high reflective mirror
TCL = thermal compensation lens
TFP = thin film polarizer
QS = Q-Switch
1/4 WP = 1/4 wave plate
GRM = gradient (Gaussian) reflective mirror

1. HR mirror prescription change 2.5 mCC to 1.0 mCC
2. The TCL focal length is “adjusted” for each cavity or slab installed, to best match thermal lensing. (TCLs ordered at a range anyway)
3. Mini-BX added to adjust for change in divergence
4. Reduction in output power from 17 mJ to 10 mJ to maintain same damage margins
5. Reduction of power allocation from 50 W to 40 W
HOMER Class Heritage and Philosophy

Design:
- Model
- Best practices
- Margins

Bread Board:
- Confirm basic performance
- Confirm “laser physics” margins
- COTS parts

Hardened bread boards/EDUs:
- Confirm mechanical margins
- Environmental/Life Testing

ETUs:
- Flight-like procedures
- Test to flight levels
- Life testing

Any change to laser is checked for impact to performance and margins

HOMER Breadboard

HOMER-1

HOMER-2

GEDI Laser

To Flight
# HOMER TRL-6 Performance Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HOMER Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>20 - 15 mJ</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>12 +/- 1 ns</td>
</tr>
<tr>
<td>Rep Rate</td>
<td>250 - 100 Hz</td>
</tr>
<tr>
<td>LDA Current</td>
<td>48-80 A</td>
</tr>
<tr>
<td>LDA Derating</td>
<td>50%</td>
</tr>
<tr>
<td>TRL 6 Mass</td>
<td>6 kg</td>
</tr>
<tr>
<td>Total QS Shots HOMER Design</td>
<td>15+ Billion</td>
</tr>
</tbody>
</table>

**Single Mode Far Field Image**  
\[\frac{D_x}{D_y} = 0.99/0.96 \text{ mRad}\]

**Laser Settings:**  
- Diode Pulse = 65us  
- \( I = 48 \text{ A} \) (~55% derated)  
- \( F = 241 \text{ Hz} \)

**Reported 01/06/2010**  
HR mirror Near Field Image  
\[\frac{W_x}{W_y} = 1.8/2.12 \text{ mm}\]

**Laser Output:**  
- \( E = 16 \text{ mJ} \)  
- Q-switch pulse ~11ns  
- Fluence < 2.5 J/cm²
The Laser module consists of:

1. Laser Cavity (pump module, laser bench)
2. Pressurized Mechanical Housing
3. Q-Switch Drive Electronics
• Incorporating all opto-mechanical lessons learned from HOMER-2, LOLA, MLA, CALIPSO, DESDYNI, & ESA’s ALADIN
• Modular design allows complete laser assembly, alignment, and substantial performance without the enclosure if necessary
• Preliminary leak rate, structural, and thermal analysis performed and will be tested
BDU Design Overview

Open Model
- KD*P Pockels cell mounts with pitch, yaw, and roll adjustments
- Rotatable 1064nm half-wave plate mount
- Rotatable/lockable YVO₄ wedge mount

Enclosure Model
- BDU enclosure
- Fused SiO₂ AR-coated windows

CBE Total Mass: ~1.81 kg
All optics, mounts, sensors, and seals (except the wedge) are either directly using or leveraging parts already being using in the HOMER laser

Telemetry:
- IEU- Tempe x2
- LEU- Pressure x2
- LEU- QS Monitor

3.5 kV at 242 Hz

10 mJ from Laser

Q-Switch Driver

LEU: 12 V
Trigger 242Hz (DU)
A few rays at “top” of Y-axis travel a different path. This produces a clipping effect, or “lobe” at the slab output end.

This creates problems for science differentiating between sloped ground and tree height.

To remove this you can either:
1) Clip off the side lobes outside the cavity
2) Make the beam smaller
3) Make the slab bigger

All options were explored and GEDI selected option 2 by changing HR Mirror curvature.

The image file is imported into a gaussian analysis model to integrate over the profiles, the quantify % energy in side lobe.

Options were reviewed externally by NESC supervised laser team from 554, 562, and expert from NGS. See GEDI-LAS-REVW-0004
**Laser Testing Performance Summary**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Energy</td>
<td>10.2</td>
<td>mJ</td>
</tr>
<tr>
<td>Frequency</td>
<td>242</td>
<td>Hz</td>
</tr>
<tr>
<td>Pump Width</td>
<td>71-77</td>
<td>μs</td>
</tr>
<tr>
<td>Current</td>
<td>55</td>
<td>A</td>
</tr>
</tbody>
</table>

**HOMER-1 1 mCC HRM Life Assessment Testing**

- No additional damage found
- HOMER-1 sensitive to temperature

**Parametric Testing:**
- Thermal lensing
- Diode distance
- End mirror tolerance

10 mJ example beam with no side lobes from GEDI-LAS-RPT-0029
Energy measurements were corrected for the LDA temperature change. Efficiency of the LDA decreases as the temperature increases.

Diodes re-inspected several times thru testing. No damage or unexpected change in performance.

Took diodes off for 1B Shot inspection and DPA

Voltage drop change

Voltage drop correction
Cavity Fluence Estimates

Energy (avg) Inside laser cavity with output coupler reflectivity \( R_{OC} = R_{GRM} \):
\[
E_{in} = E_{out} \times \frac{(1 + R_{GRM})}{(1 - R_{GRM})}
\]

But our reflectivity changes with beam size on the GRM, so we have to estimate:
\[
R_{GRM} = \frac{1}{a^2} \cdot \int_0^2 \int_0^a R_0 \cdot \exp\left[ -\frac{2r^2}{w^2} \right] \cdot r \cdot dr \cdot dq
\]

... To get the operational damage margin for each optic:
\[
M_D = \frac{LIDT}{calc}
\]

So we can calculate the fluence on each optic:
\[
calc = E_{in} \times \frac{2}{2^{2}}
\]

<table>
<thead>
<tr>
<th>Meas LIDT (J/cm²) ( LIDT )</th>
<th>Calc Fluence (J/cm²) ( calc )</th>
<th>Margin ( M_D )</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>Risley Pair</td>
<td>TCL</td>
<td>Slab Face</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Meas LIDT (J/cm²) ( LIDT )</td>
<td>11.5</td>
<td>44</td>
<td>25</td>
</tr>
<tr>
<td>Calc Fluence (J/cm²) ( calc )</td>
<td>1.75</td>
<td>1.95</td>
<td>2.08</td>
</tr>
<tr>
<td>Margin ( M_D )</td>
<td>4.2</td>
<td>22.6</td>
<td>15.3</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.32</td>
<td>0.36</td>
<td>0.37</td>
</tr>
</tbody>
</table>

*worst case: round beam at GRM-end of slab
<table>
<thead>
<tr>
<th>ID</th>
<th>Requirement</th>
<th>Values</th>
<th>FT</th>
<th>CPT</th>
<th>Life test</th>
<th>Technique Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laser Wavelength</td>
<td>1064.5 nm ± 0.2 nm in vacuum</td>
<td>x</td>
<td>O</td>
<td></td>
<td>Pickoff beam. Use built in software to calibrate measurement for vac. Take vacuum and air values</td>
</tr>
<tr>
<td>2*</td>
<td>Laser Output Energy</td>
<td>10 mJ ±5% fully captured beam at the output</td>
<td>x</td>
<td>x</td>
<td>C</td>
<td>Measuring Total Output Energy using energy meter with 10ms integration time. CPT - energy meter put at the end of the snout to get full output. Used to calibrate pickoff measurement as well FT/Lifetest - calibrated pickoff</td>
</tr>
<tr>
<td>3*</td>
<td>Far-Field Divergence of the Central Lobe</td>
<td>0.6 mrad ±0.08 mrad 1/e² div.</td>
<td>x</td>
<td>x</td>
<td>C</td>
<td>Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing for side lobes FT-50 cm lens CPT - Rayleigh Range</td>
</tr>
<tr>
<td>6</td>
<td>Laser Output Polarization Ratio</td>
<td>≥ 200:1</td>
<td>x</td>
<td>O</td>
<td></td>
<td>Measure by hand using wave-plate/hi ratio polarizer configuration</td>
</tr>
<tr>
<td>9</td>
<td>Pulse Repetition Rate</td>
<td>242 ± 2 Hz</td>
<td>x</td>
<td>x</td>
<td>C</td>
<td>Confirm pulse with Tektonix 2024C and use e-drive output reading for continuous measurement</td>
</tr>
<tr>
<td>10</td>
<td>Pulse Width</td>
<td>&lt;16ns Full-width and half-max</td>
<td>x</td>
<td>x</td>
<td>C</td>
<td>FT- 200 MHz Oscilloscope Average of 16 captures of laser pulses CPT -2 GHz scope. High speed Oscilloscope compiling 10,000 shots with histogram through computer analysis and post processing. LMB will be measured as well.</td>
</tr>
<tr>
<td>12</td>
<td>Laser Pulse Energy Concentration in Far-Field Outside of Central Lobe</td>
<td>≤ 0.5% of 1/e² Central Lobe per energy concentration</td>
<td>x</td>
<td>O</td>
<td></td>
<td>Spiricon camera (raw beam data) 5-10 captures Computer Analysis and post processing</td>
</tr>
<tr>
<td>13*</td>
<td>Number of Laser Shots for Life Testing</td>
<td>3.2 billion shots</td>
<td>x</td>
<td>x</td>
<td>C</td>
<td>GSE shot counter will monitor shots for every test. ETU life time shot count will be monitored continuously</td>
</tr>
<tr>
<td>24</td>
<td>LDA Operating Temperature</td>
<td>35 +/- 2 °C</td>
<td>x</td>
<td>C</td>
<td></td>
<td>Internal 10k thermistors read by EGSE</td>
</tr>
</tbody>
</table>

O = Occasional  
C = Continuous  
X = One Time  
Measurement
- Environmental Testing performed on ETU and Flight units
  - ETU: Vibration, TVAC, EMC, and life test
  - Flight: Vibration, TVAC, EMI/C (at instrument level)
  - CPTs before and after each test (or specific cycles)
- Interface testing: BDU, LEU, DOE

<table>
<thead>
<tr>
<th>Level of Assembly</th>
<th>Item</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Hardware Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Laser</td>
<td>GSFC</td>
<td>3</td>
<td>PF</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Structural Mechanical</th>
<th>EMI/EMC &amp; Magnetics (1,2)</th>
<th>Thermal / Vacuum (3)</th>
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<tbody>
<tr>
<td>Modal Survey</td>
<td>Mass Properties</td>
<td>Pressure Test</td>
</tr>
<tr>
<td>Strength - Design Loads (1,1)</td>
<td>Conduction Emissions</td>
<td>Thermal Balance</td>
</tr>
<tr>
<td>Sine Survey (Sine Sweep)</td>
<td>Conducted Susceptibility</td>
<td>Ambient</td>
</tr>
<tr>
<td>Sine Vibration</td>
<td>Radiated Susceptibility</td>
<td>Mechanical Function</td>
</tr>
<tr>
<td>Random Vibration</td>
<td>Self Compatibility</td>
<td>Life Tests</td>
</tr>
<tr>
<td>Acoustics</td>
<td>EMI/EMC &amp; Magnetics (AC)</td>
<td>Bakeout</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>Magnetic Properties (DC)</td>
<td></td>
</tr>
<tr>
<td>Mechanical Function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure Profile</td>
<td></td>
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<tr>
<td>Torque Ratio</td>
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<tr>
<td>Life Tests</td>
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<tr>
<td>Mass Properties</td>
<td></td>
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<tr>
<td>Interface Tests</td>
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<tr>
<td>Conduction Emissions</td>
<td>Conducted Susceptibility</td>
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<tr>
<td>Conducted Susceptibility</td>
<td>Radiated Susceptibility</td>
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</tr>
<tr>
<td>Radiated Emissions</td>
<td>Self Compatibility</td>
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<tr>
<td>Self Compatibility</td>
<td>Magnetic Properties (AC)</td>
<td></td>
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<tr>
<td>Magnetic Properties (DC)</td>
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<tr>
<td>Leak Test</td>
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<tr>
<td>Pressure Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Vacuum # of Cycles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Balance - Ambient # of Cycles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakeout</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Optical Setup – Laser Lifetest w/BDU

Laser & BDU Lifetest Optical Table (8' x 4')
ETU Laser Development Flow

Start Build

GSE
- Optical Parts Procurement
- Mechanical Fabrication
- Electrical
  - SLAC Repair

Preparation 1/16
- Acceptance Testing
- Harnessing
- Bonding
- Kitting & Inspection

Sub-Assembly 3/16
- Pump Module
- Optical Bench
- Enclosure
- Q-switch Driver

Laser Module Assembly 4/16
- Integrate Pump Module and Optical Bench
- Integrate Electronics
- Test Cavity Performance
- Integrate Enclosure
- CPT
- Special Testing*

Environmental Testing 5/16
- Vibration/CP T
- EMC
- TVAC/CPT
- Interface Test

TRR

Start Life Testing 5/16

Legend
- Parts Ordered
- Parts Delivered
- Paperwork Release
- Complete Task
- Complete
- Monitor - no tech/cost/schd impact
- Monitor - tech/cost/schd impact
- On Plan

*Special testing includes pressure and temperature cycling
Laser Assembly Flow

Assemble bucket:
- Flexures
- QSD
- Harness

Workmanship Test Seals (Qualify on ETU)

Add Pump Module:
- Safe-to-mate GSE
- Test Fire Diodes
Laser Assembly Flow

Add Laser Optical Bench & Bench Optics

- Functional Test: LASER-2,3,9,10,11
- Special Test:
  - Lab Temp Cycle
  - FT every 0.5 C

Seal Enclosure

- Comprehensive Performance Test:
  - LASER-1,2,3,4,5,6,7,8,9,10,11,12,15,18,19,20,21
- Special Test:
  - Lab Pressure Test
  - FT min/nom/max pressure

Environmental & Interface Testing

- Special Test:
  - Lab Temp Cycle
  - FT every 0.5 C
Laser ETU Bucket and Driver Assembly

“Bucket” Enclosure

Titanium Flexure

Q-switch Driver
Laser ETU Diode and Bench Assembly
BDU ETU Assembly Test Configuration

- Q-switches
- Crystal
- Functional Test Platform
- TVAC Testing