The Advanced Topographic Laser Altimeter System (ATLAS) for NASA’s Ice Cloud and Land Elevation Satellite-2 (ICESat-2)

Design, Development, and On-Orbit Performance

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ATLAS Measurement Concept

Measurement concept drives ATLAS
Key Performance Parameters:
- Radiometry (signal & stray light)
- Alignment (internal & external)
- Timing (precision & bias)

ATLAS wants to know elevation
ATLAS measures range (time of flight) and absolute pointing

Other elements finish the task:
Spacecraft Star Tracker/Inertial Measurement Unit, Global Positioning System, ground-based Satellite Laser Ranging
ICESat Background

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• ICESat
  • Launch : January 13, 2003
    • Decommissioned August 17, 2010
  • Instrument : Geoscience Laser Altimeter System (GLAS)
    • Diode Pumped-Nd:YAG Solid-state laser transmitter
      • 4-ns pulse
      • 40-Hz Pulse Repetition Frequency
      • 1064-nm altimeter
        • 70-m footprint
      • 532-nm atmospheric sounder
  • 1-m telescope receiver
  • Silicon –Avalanche Photodiode (Si-APD) altimeter detector
    • Analog waveform capture
    • Single Photon Counting Modules (Geiger-mode Si-APDs) for atmospheric detectors
      • Photon-counting atmospheric profiles
  • Despite laser issues, ICESat collected a valuable dataset used to evaluate global ice sheets
    • This set the stage for ICESat-2
ATLAS Design
Instrument Overview

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- **Transmitter**
  - Solid-state Nd:YVO<sub>4</sub> Master Oscillator Power Amplifier (MOPA) Architecture
  - 10-kHz pulse rate
  - 1.2-ns output pulses
  - 532.292-nm wavelength, tunable ±15 picometers
  - Diffractive beam splitter
    - 6 signal beams: 3 strong, 3 weak

- **Receiver**
  - 80-cm reflector telescope
  - 30-pm bandpass filter
    - Temperature-tuned to match transmitter
  - Single photon detection w/ 16-pixel photomultipliers

- **Timing**
  - 100-MHz Ultra Stable Oscillator w/ gate-delay Field Programmable Gate Array (FPGA)
  - Range tracking algorithm utilizing on-board Digital Elevation Model/Digital Relief Model and position/attitude updates from spacecraft

- **Alignment**
  - Active Transmit/Receive co-boresight alignment
    - Alignment Monitoring and Control System (AMCS)
ATLAS Ground Track Illumination Pattern

- Diffractive Optical Element (DOE) splits single input laser beam into 6 beams
- 3 x 2 array – 3 "Strong", 3 "Weak"
  - 4:1 energy ratio (Strong:Weak)
- 13.22 x 5.0 mrad angular separation
- Each spot <25µrad divergence (same as input beam)
  - Each spot is ~12 m diameter on ground

**Transmit Pattern**

WEAK: 25 µJ /spot

STRONG: 100 µJ /spot
Pulse energy: ~250 μJ – 900 μJ/pulse, programmable
Master Oscillator – Power Amplifier
  Diode laser end-pumped Nd:YVO₄
Oscillator:
  Volume Bragg Grating output coupler for wavelength control
  Active Q-switch
Nd:YVO₄ slab fractured during test in 2016, prompting re-design
  Design for flight:
    Eliminated gold plating
    Minimized mount induced stresses on slab
    Selected crystals with the fewest flaws
ATLAS Receiver

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- **Telescope**: 80-cm Ritchey-Chretien Cassegrain
  - Fiber optics at focal plane couple received signals through temperature-controlled optical filters (30-pm bandwidth) to detector array
- **Detectors**: Hamamatsu R7600-300-M16 Green Extended Cathode Photomultipliers (PMT, qty. 6):
  - 16 channels Constant Fraction Discriminator (CFD) design for strong spots
  - 4 channels Constant Fraction Discriminator design for weak spots - 4 pixels are combined as one CFD channel.
• Photon Counting Electronics
  • Time-tag each detected photon event from the Detector Electronics Module
    • Range gate determined by an on-board algorithm using
      • Digital Elevation/Relief maps (World Geodetic System 1984 ellipsoid)
      • Real-time spacecraft position and attitude (1-Hz, interpolated)
    • 100-MHz oscillator referenced to GPS 1-pps provides coarse time count
    • Gate delay FPGA provides fine time count with ~150-ps resolution
    • Time tags are histogrammed and likely ground signal selected for downlink by evaluating background, signal strength over time, and cloud cover
ATLAS Instrument Overview

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>MASS</td>
<td>470 kg</td>
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<td>POWER</td>
<td>420 W</td>
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<td>DAILY DATA VOLUME</td>
<td>~500 Gbits</td>
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On orbit laser pulse energy: 450 µJ
ATLAS Transmit Optics Lifetime

- **Transmit Optics Lifetime**
  - Optical coatings exposed to laser beams in vacuum tend to damage/degrade
  - ATLAS lifetime requirement = 1T shots
  - Mitigations:
    - Maintain 1 atm pressure inside laser
    - Expand laser beam inside pressurized laser before impinging on transmit optics in vacuum
    - Perform Laser Induced Damage Threshold testing to screen all optics
    - House transmit optics in heated enclosure to maintain temperature at 20°C
  - Optical Coatings Life Test (OCLT)
    - Exposed coated optics to laser energy with varying levels of expected contaminants in vacuum.

Typical Beam Quality Degradation

Start

1 T shots

1.5 T shots
ATLAS GSE Bench Checkout Equipment

LOAS
Laser Optical Attenuator and Sampler
- Attenuates/stops and samples ATLAS laser beam
  - Neutral Density filter stack
- Single mode fiber pick-off
- Integrating Sphere

MAAT
Main Alignment & Altimetry Target
- Retro-reflector & beam steering
  - Laser Beam Diagnostics
    - Camera, Integrating Sphere, Fiber pickoff

Star Target
Fixed star pattern for LRS

OTPSS
Optical Test Port Stimulator System
Diode laser sources, delay generators fiber coupled to ATLAS

Receiver Telescope
Aperture Cover
- Path for aperture signal sources
  - Showerhead
- Thermal target
- Stray light block
Launch on the last Delta-II

15 September 2018, 13:02

Delta II 7420-10C
ATLAS Instrument Performance
Transmitter

• Laser energy
  • Stable to within ±2% of ground test values

• Beam Quality
  • Nominal as indicated by slope of Alignment Monitoring and Control System (AMCS) sweeps
    • Plots show received beam convolved with RTA field of view

• Pointing
  • No change post-launch
  • Orbit variation ~30 µrad p-p

ATLAS LASER SHG Output Energy
First Six Months On Orbit

Laser energy reduced to optimize link

600 µJ
450 µJ

Transmitter Laser energy
reduced to optimize link
ATLAS Instrument Performance
Receiver

- Receiver performance nominal
  - Impulse response as expected (Transmit Echo Pulse)
  - Solar background noise as expected

Photomultiplier responding to radiation over South Atlantic Anomaly prior to opening of aperture door. Counts are much lower than solar background rates.
Receiver Algorithms On-Orbit Example
Track over the Himalayas

Telemetry Bands in Range Windows

Atmospheric Histogram Plot
- With the strong beam, there is a well defined wave structure.
- This example depicts wavelengths on the order of 140 m.

Figure courtesy of Brad Klotz
ATLAS Observations
Trees in Russia, daytime acquisition
ATLAS Observations
Australian Coast (NW) ATL03 Transect

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Trees at coast

More photons under the water surface due to volume scattering

Waves on ocean

9 m

~26 m

Bathymetry
First three weeks of observations over Antarctica
Atmospheric Observations
Smoke from California Fires

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Yuekui Yang GSFC
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## Acronyms

<table>
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<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AMCS</td>
<td>Alignment Monitoring and Control Subsystem</td>
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<tr>
<td>ATLAS</td>
<td>Advanced Topographic Laser Altimeter System</td>
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<tr>
<td>AZ</td>
<td>Azimuth</td>
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<tr>
<td>BCE</td>
<td>Bench Check-Out Equipment</td>
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<tr>
<td>BSM</td>
<td>Beam Steering Mechanism</td>
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<tr>
<td>CCHP</td>
<td>Constant Conductance Heat Pipe</td>
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<tr>
<td>CFD</td>
<td>Constant Fraction Discriminator</td>
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<tr>
<td>DAA</td>
<td>Detector Array Assembly</td>
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<tr>
<td>DEM</td>
<td>Detector Electronics Module</td>
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<tr>
<td>DOE</td>
<td>Diffractive Optical Element</td>
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<td>DOM</td>
<td>Detector Optics Module</td>
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<tr>
<td>DRM</td>
<td>Digital Relief Model</td>
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<tr>
<td>EL</td>
<td>Elevation</td>
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<tr>
<td>FM</td>
<td>Fold Mirror</td>
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<tr>
<td>HV</td>
<td>High Voltage</td>
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<td>ICESat-2</td>
<td>Ice Cloud and Land Elevation Satellite - 2</td>
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<tr>
<td>IMSC</td>
<td>Instrument-Mounted Spacecraft Components</td>
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<tr>
<td>LHP</td>
<td>Loop Heat Pipe</td>
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<tr>
<td>LRS</td>
<td>Laser Reference System</td>
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<tr>
<td>LSA</td>
<td>Laser Sampling Assembly</td>
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<tr>
<td>MOPA</td>
<td>Master Oscillator - Power Amplifier</td>
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<td>Nd:YAG</td>
<td>Neodymium-doped Yttrium Aluminum Garnet</td>
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<tr>
<td>Nd:YVO4</td>
<td>Neodymium-doped Yttrium Orthovanadate</td>
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<tr>
<td>PBC</td>
<td>Polarization Beam Combiner</td>
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<tr>
<td>PMT</td>
<td>Photomultiplier</td>
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<tr>
<td>RTA</td>
<td>Receiver Telescope Assembly</td>
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<tr>
<td>SHG</td>
<td>Second Harmonic Generator</td>
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<td>Si-APD</td>
<td>Silicon Avalanche Photodiode</td>
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<tr>
<td>SPCM</td>
<td>Single Photon Counting Module</td>
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<tr>
<td>TAMS-LS</td>
<td>Telescope Alignment Monitoring System Light Source</td>
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<tr>
<td>USO</td>
<td>Ultra Stable Oscillator</td>
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