ICESat-2/ATLAS: How Does ATLAS Work?

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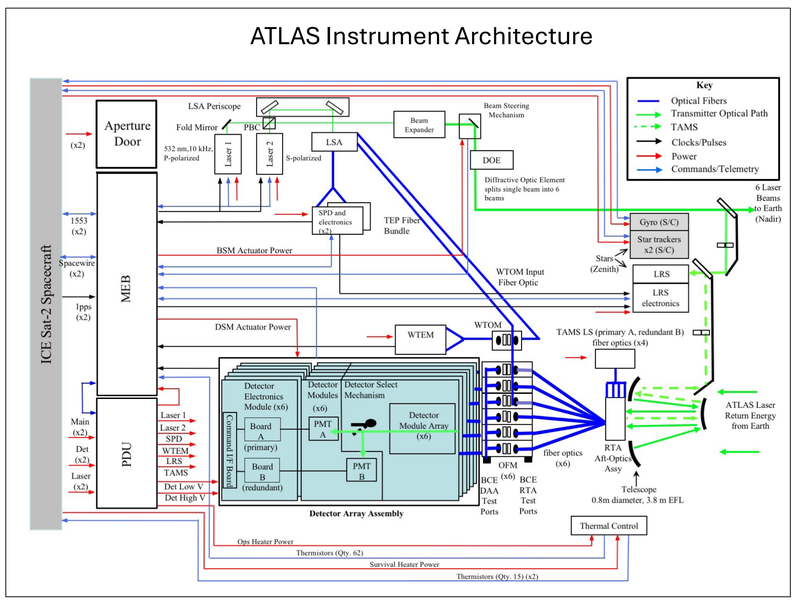
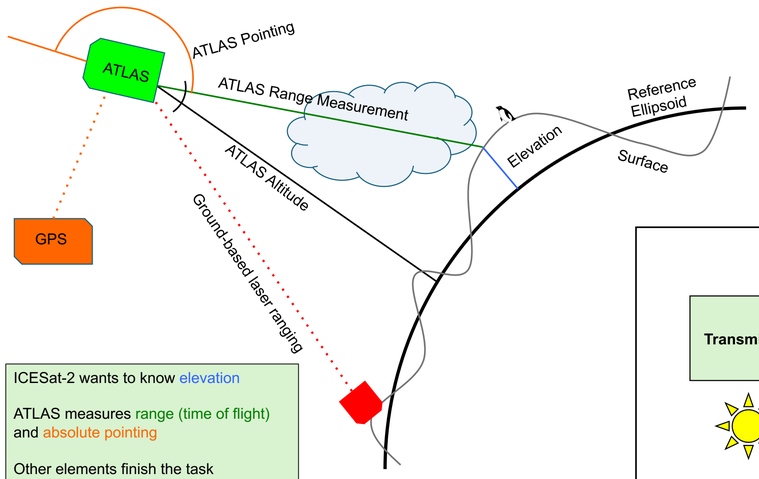
The Advanced Topographic Laser Altimeter System (ATLAS) is the scientific instrument on ICESat-2. It is a six-beam lidar uses 532-nm pulsed laser light and a single-photon-sensitive receiver to measure two-way travel time of photons between the spacecraft and the surface. When combined with spacecraft position and attitude data, these measurements allow the ground bounce point (latitude, longitude, and height) of each photon to be determined in ground processing. The instrument's major subsystems include a transmitter that sends out laser pulses in six beams, a receiver that collects returned light and sends it into six independent detection/timing chains, and an alignment monitor/control system that keeps the beams pointed where the receiver is looking and reports the pointing directions of the beams.

ATLAS Instrument Architecture



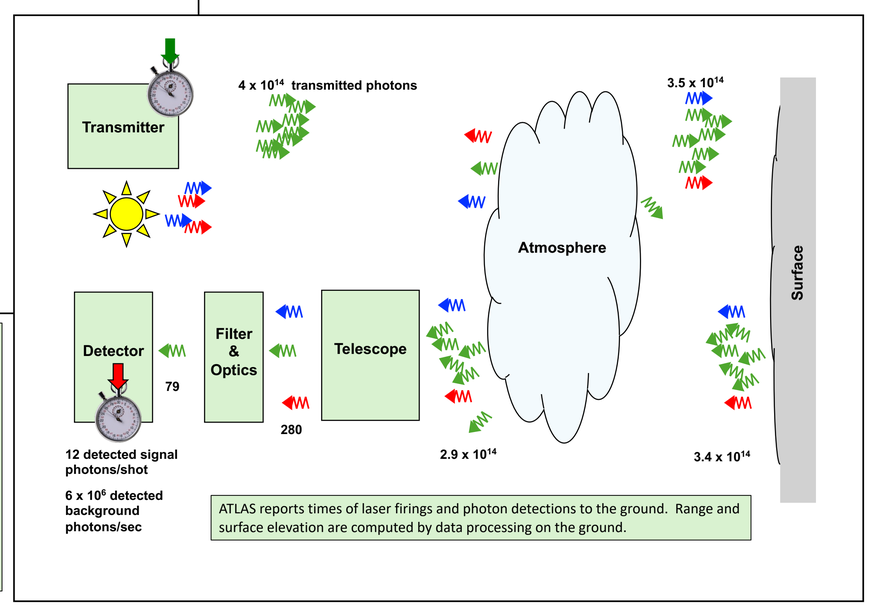
Measurement Geometry



ICESat-2 wants to know elevation

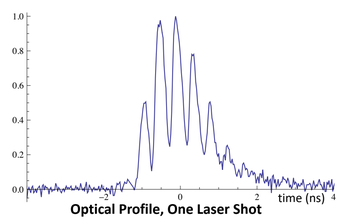
ATLAS measures range (time of flight) and absolute pointing

Other elements finish the task



ATLAS reports times of laser firings and photon detections to the ground. Range and surface elevation are computed by data processing on the ground.

Transmitted Pulse

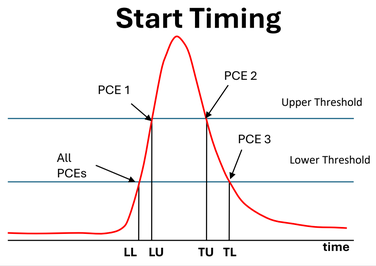


Optical Profile, One Laser Shot

A single transmitted optical pulse contains multiple peaks (due to beating between mode frequencies of the laser) under an envelope.

A sample of the transmitted pulse is detected by the Start Pulse Detector (SPD). The SPD is followed by a low-pass filter that smooths out the peaks, leaving only the envelope.

Start Timing



A digital edge is generated as the leading and trailing edges of the filtered start pulse cross each of two adjustable thresholds.

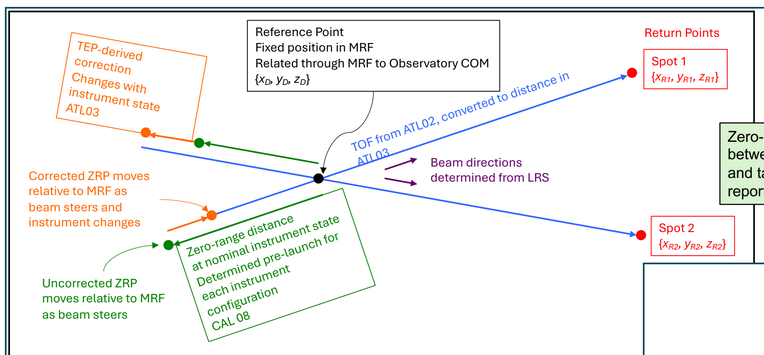
Each of the three Photon-counting Electronics (PCE) cards receives the leading-lower crossing edge and one of the other three crossing edges.

The threshold-crossing edges are timed by the same circuitry that times the pulses corresponding to return photons.

The start time is computed as the mean of the four threshold-crossing times.

The laser fires at 10 kHz with pulse width approximately 1.3 ns and energy commandable between 250 and 1400 μJ. A small fraction of the energy is sampled for internal use within the instrument. After the laser beam goes through a beam expander and diffractive optical element, it exits the instrument as six beams, each with a diameter about 44 mm and divergence about 24 μR, illuminating an area on the ground 11 m in diameter. The beams illuminate a 2x3 rectangular pattern on the ground with the the short side of the rectangle at a slight angle to the direction of travel, so the tracks of the beams form three closely-spaced pairs, each containing a "strong" beam and a "weak" beam. The laser pulse energy setting is chosen to provide approximately 12 photoelectrons per shot in each strong beam's return from a snow surface under a clear sky.

Range Measurement



Zero-range distance = distance between ATLAS reference point and target for which ATLAS reports zero time of flight

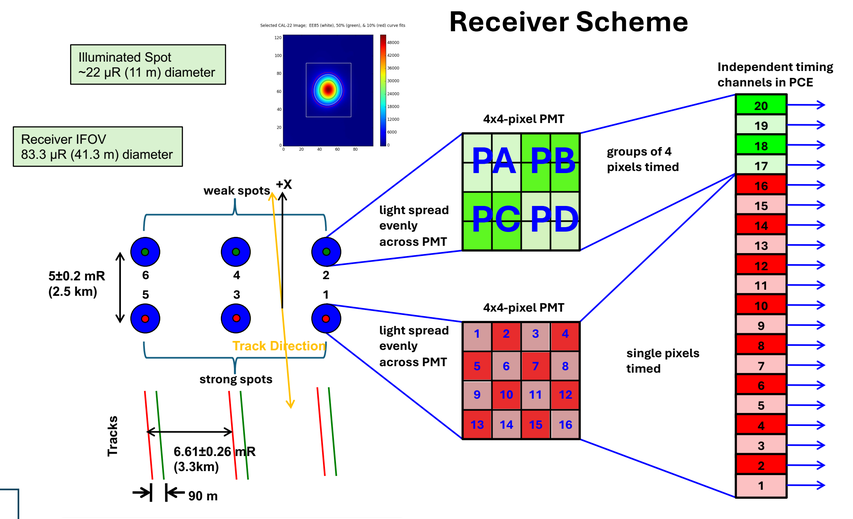
Range bias calibrated before launch (CAL 08)
- direct measurement for Spot 3 using target at known position
- spot-to-spot differences vs. temperature using target at changing position

Change in TEP time of flight on orbit indicates change of range bias
- observed at least once per orbit

The receiver contains a telescope that images each of the laser spots on the surface onto a separate optical fiber, which acts as a field stop. Each fiber leads to a solar-blocking filter, then through another optical fiber to a photon-counting detector that produces a digital edge for each photon detection event. Individual events are timed with approximately 200 ps precision, and on-board software selects for telemetry those events that are determined to be within a band around the surface. In addition, an "atmospheric histogram" is telemetered, containing counts of events in 200 ns bins accumulated over 400 laser shots.

Energy sampled from the laser beam is used to measure the laser's firing time, track the wavelength tuning of the background filters, and monitor changes to the instrument's impulse response and timing bias.

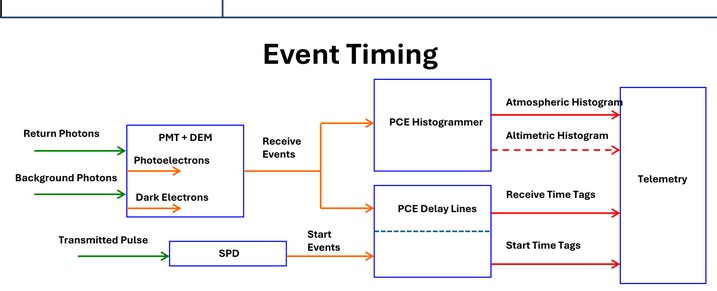
Receiver Scheme

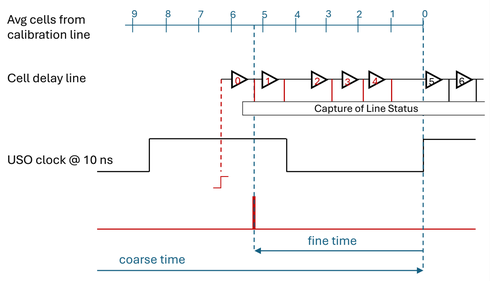


Weak and strong spots maximize the penetration of a given total laser energy. Clocking of pattern with respect to velocity separates tracks.

Light from each spot illuminates its own detector. Light illuminating each detector is divided among multiple independent timing channels to reduce the effects of dead time.

Event Timing





Each event's time is measured by
- coarse time (edge of 10 ns clock)
- fine time (position of edge in delay line)

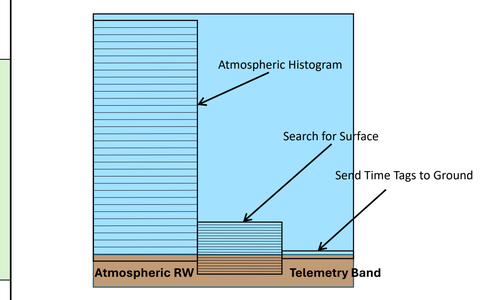
CAL 17 corrects fine time for varying widths of delay line cells
- measured by histogramming fine times of background events

CAL 44 corrects for time skews between start time channels
- measured by collecting start times as threshold values are varied, then adjusting so curves match pulse shape

CAL 49 corrects for time skews between receiver channels within a spot
- difference between time of flight centroid for each channel and mean centroid

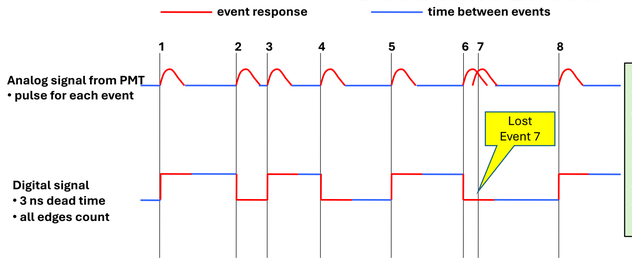
CAL 17, CAL 44, and CAL 49 are based on a combination of pre-launch measurements and on-orbit data.

The telemetry from ATLAS includes fire times, detection times, atmospheric histograms, and spot centroids, as well as hundreds of other instrument parameters. These data are turned into time of flight, range, and pointing direction by the ground system.



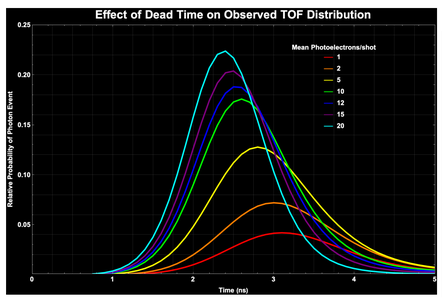
Telemetering time tags for all events would result in an unacceptably high data volume. An on-board algorithm defines a band about the surface and selects for telemetry only the time tags within the band.

Dead Time Effects



If two photoelectrons occur in the same channel too close together, only one digital edge will be generated. The minimum spacing (dead time) is about 3 ns.

The combination of analog and digital circuitry in each channel exhibits both *paralyzable* (lost event restarts the dead time) and *nonparalyzable* (lost event does not restart the dead time) effects.



The effects of dead time include
- radiometry: the total number of events is not proportional to the total number of photons
- timing: the time-of-flight distribution shifts toward shorter times at higher illumination

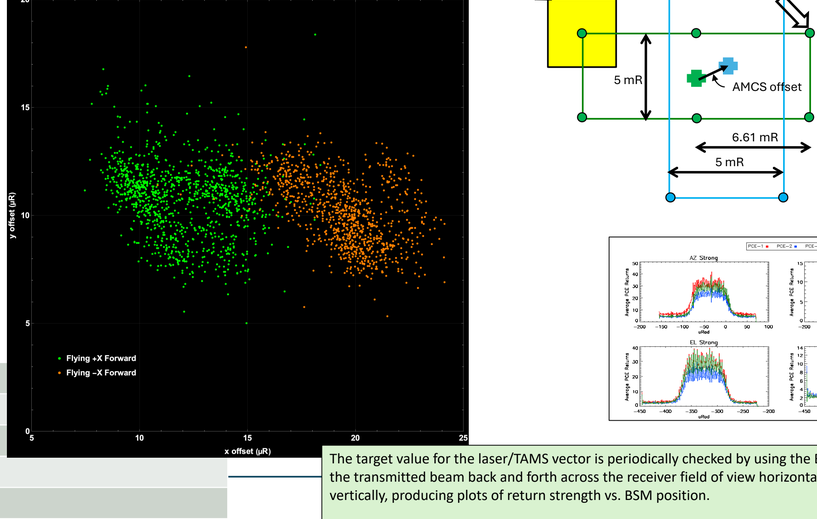
For up to about 20 photoelectrons/shot, the effect of dead time can be simply modeled. CAL 19 and CAL 34 provide tables to correct the radiometric and timing effects based on such a model, and the ATL06 algorithm has a different model built in.

Significantly higher levels of illumination, such as from specular reflections, result in distortions that cannot be corrected by a simple model. Work is ongoing on a model for such cases.

Centroids of the laser spot pattern (reflecting the transmitter pointing) and the TAMS spot pattern (reflecting the receiver pointing) are computed in an on-board control loop using data from the LRS laser camera. The position of the Beam-Steering Mechanism (BSM) is commanded to maintain the vector between the two centroids at a target value to within about 1 μR RMS.

Retroreflected samples of the transmitted beams are imaged onto the Laser Reference System camera, along with beams projected from the telescope focal plane. Software uses the beam images and steering mechanism to maintain the alignment between the transmitter and receiver.

Transmitter/Receiver Alignment



The target value for the laser/TAMS vector is periodically checked by using the BSM to swing the transmitted beam back and forth across the receiver field of view horizontally and vertically, producing plots of return strength vs. BSM position.

The optimal target value is determined from the center of the high flat region.

The optimal target value varies over time, particularly as a function of which side of the observatory is facing the sun.

Orbital Altitude	481 to 511	km	
Laser Firing Rate (nominal)	10	kHz	
Transmitted Energy (typical strong beam)	48 to 172	μJ	Adjustable in 11 steps
Transmitted Energy (typical weak beam)	12 to 43	μJ	Nominally ¼ of strong beam energy
Transmitted Wavelength	532.272	nm	
Transmitted Beam divergence, 85% enclosed energy (typical)	22	μrad	
Transmitted Beam Eccentricity	0.4	none	
Transmitted Beam Angular Spacing (long dimension)	6.6	mrad	approximately across track
Transmitted Beam Angular Spacing (short dimension)	5	mrad	approximately along track
Pointing Direction (nominal)	N/A	N/A	Nadir is along the centerline of cross-track direction of the beam pattern. Position along the centerline varies with roll.
Track Pair Spacing (nominal)	90	m	spacing between weak and strong track in the same pair, at 500 km altitude
Receiver Aperture Diameter	0.802	m	
Receiver Aperture Effective Area	0.41	m^2	Less than aperture circular area due to obstruction in telescope
Receiver Field of View Angular Diameter	83.5	μrad	
Receiver Optical Throughput (typical at peak wavelength; does not include obstruction in telescope)	.41	none	Best-estimate actual products of receiver throughput and efficiency are in ATL02
Receiver Counting Efficiency (typical)	0.15	none	
Receiver Effective Optical Bandwidth	38	pm	Rectangular band at peak wavelength throughput
Event timing precision (typical)	200	ps	Width of delay-line cell
Single-photon time-of-flight uncertainty (typical standard deviation)	800	ps	Dominated by transmitted pulse width