The Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL): A Spaceflight Prototype

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Abstract: We report on progress in developing a new swath mapping laser altimeter measurement approach for future spaceflight missions using a short-pulse laser transmitter, beam-splitting to form multiple cross-track beams, photon counting detectors, high-precision event timers and a high-throughput data system.

1. Introduction

The Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL) is an airborne prototype in development to demonstrate laser altimetry measurement methods and components that enable efficient, high-resolution, swath mapping of topography and surface properties from space. SIMPL accomplishes laser ranging by means of single photon detection and differentiation of surface types by measuring the degree of depolarization that occurs during reflection of plane-polarized laser pulses. Laser backscatter depolarization, a function of composition and micro-roughness, is a measure of the proportion of photons that undergo single- and multiple-scattering reflection from a surface. This instrument development is sponsored by the NASA Earth Science and Technology Office (ESTO). In their 2004 Instrument Incubator Program (IIP) solicitation, ESTO requested proposals for advanced topographic mapping instruments capable of providing precise elevation images for detailed monitoring of ice sheets, sea ice and glaciers. Although focused on these polar-region cryosphere objectives, the SIMPL measurement approach is also applicable in other scientific applications where high-resolution imaging of land surface topography and vegetation structure is important.

2. Measurement Approach

Prior work has demonstrated photon counting laser altimetry at green wavelengths using Photomultiplier Tube (PMT) detectors, including the Multikilohertz Photon-Counting Microlaser Altimeter (MMLA) development conducted in an earlier IIP project [1]. However, laser altimeters operating in the near-infrared (NIR) have efficiency advantages as compared to visible wavelengths, including higher atmospheric transmission, reduced solar background noise, higher reflectance for most land covers and elimination of the need for frequency doubling of NIR lasers. SIMPL will demonstrate photon counting laser altimetry at both NIR (1064 nm) and green (532 nm) wavelengths employing Single Photon Counting Modules (SPCM), the only mature detector capable of single photon detection at both wavelengths. By operating at both wavelengths depolarization ratio data in the visible and NIR will be obtained enabling assessment of their utility in differentiating surface types. Earlier work documented that laser depolarization at 532 and 1064 nm differentiates needle-leaf and broad-leaf vegetation based on differences in their wavelength-dependent scattering properties [2]. Lab measurements conducted in this effort of snow, ice, liquid water and sand further demonstrated discrimination of these targets based on wavelength-dependent depolarization differences.

Use of SPCM detectors, required to obtain both NIR and visible data, imposes a significant constraint. Their long-dead time between detection of single photons requires low probability of detection ($PD < 1$) per laser fire to avoid biasing the range data and shielding of the ground by overlying vegetation. High laser pulse repetition rates are therefore needed to achieve sufficiently dense sampling of rugged topographic surfaces and vegetation structure, necessitating continuous, un-gated detector operation. Therefore solar background noise count rates must be stringently controlled by means of narrow bandwidth filtering and a small detector field of view. Figure 1 conceptually compares traditional analog detection, PMT-based photon counting with $PD > 1$ and SPCM-based photon counting with $PD < 1$.

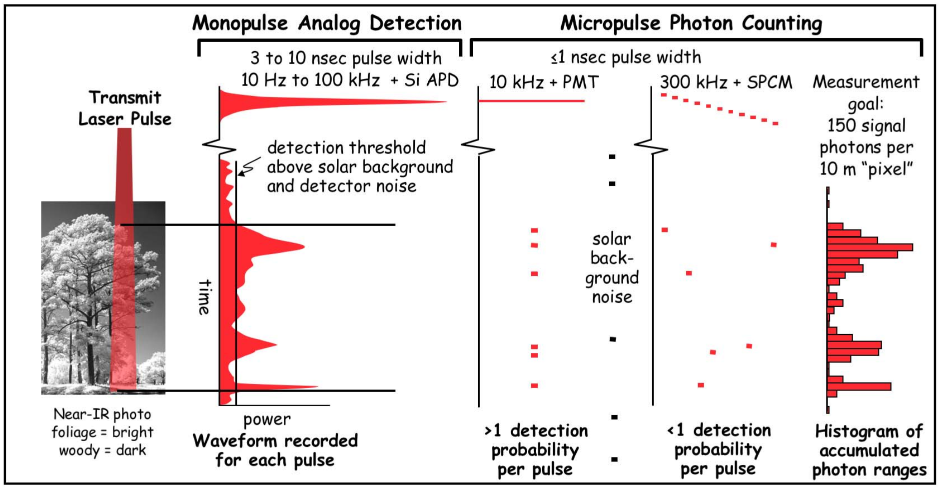

Figure 1. Conceptual illustration of laser ranging approaches, including analog detection, photon counting utilizing a PMT detector and PD > 1 per pulse and photon counting utilizing a SPCM detector and PD < 1 per pulse.

3. Instrument Implementation

The SIMPL instrument utilizes the proven optical bench and monostatic off-axis parabola telescope design employed in the MMLA instrument, with transmitter and receiver components mounted on opposite sides of the bench (Figure 2). Both the transmitter and receiver architecture are new to SIMPL. The transmitter employs a short-pulse (~1 nsec) NIR laser source (a 10 kHz microchip laser or a 300 KHz fiber laser custom built by IPG for this project), a frequency doubling crystal producing NIR and green output, and calcite beam displacers to producing four cross-track beams with co-aligned green and NIR pulses. In the receive path the four beams are imaged onto a four-pinhole field stop and passed through a collimating lens. A dichroic beam splitter separates the green and NIR signals and polarizing beam splitters then separate the parallel- and cross-polarized signals, yielding sixteen-channel data. Each output channel is fiber coupled through narrow-band filters to one of sixteen SPCM detectors. Photon detection events are timed with 250 psec resolution using four multi-plexed, GPS-disciplined timer cards. To accommodate very high photon count rates (2 mega-events per sec per channel), expected for worst case noise conditions due to a high solar zenith angle and a highly reflective surface, PCI-X bus data transfer and a very high-throughput CPU motherboard are employed. The 64-bit time-tagged data arrays are written to a RAID hard disk array at rates up to 256 mega-bytes/sec, equivalent to 1 terra-byte/hr. Sample data from a one-beam, four-channel lab breadboard and integration and test of the sixteen-channel flight instrument will be described.

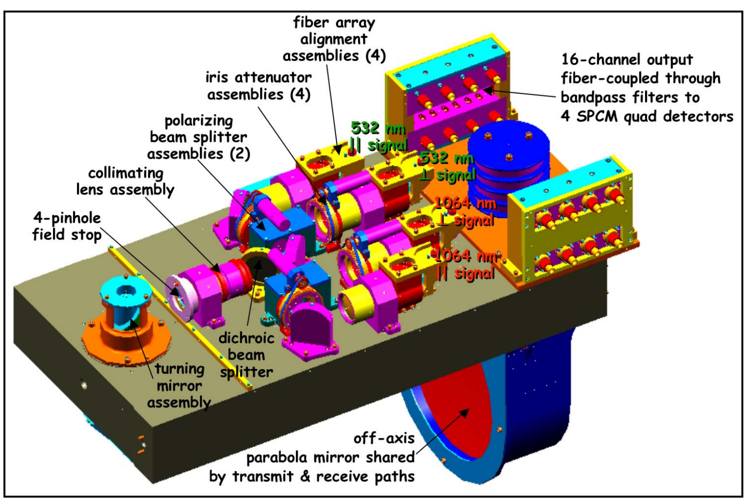

Figure 2. Mechanical schematic of the SIMPL optical bench and receiver-side components.

4. References

1. J. Degnan et al. (2001), "Design and Performance of an Airborne Multikilohertz Photon-Counting, Microlaser Altimeter", *Proc. ISPRS Workshop on Land Surface Mapping and Characterization Using Laser Altimetry*, October, 2001, Annapolis, MD.

2. J. E. Kalshoven, Jr., and P. W. Dabney (1993), Remote Sensing of the Earth's Surface Using an Airborne Polarized Laser, *IEEE Trans. Geosci. Remote Sensing*, 31, 438–446.