

EFFICIENT SWATH MAPPING LASER ALTIMETRY DEMONSTRATION INSTRUMENT INCUBATOR PROGRAM

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ABSTRACT

In this paper we will discuss our eighteen-month progress of a three-year Instrument Incubator Program (IIP) funded by NASA Earth Science Technology Office (ESTO) on swath mapping laser altimetry system. This paper will discuss the system approach, enabling technologies and instrument concept for the swath mapping laser altimetry.

1. INTRODUCTION

NASA Goddard Space Flight Center (GSFC) is developing an airborne instrument under the Swath Mapping IIP with the objectives to advance the key technologies and mitigate some of the risks associated with the Lidar Surface Topography (LIST) mission. The key attributes of the LIST mission, as described in the NRC Earth Science Decadal Survey report, are: (1) a medium cost mission to be launched by NASA between 2016-2020; (2) a single-instrument payload carrying an imaging lidar at low Earth orbit; (3) one-time global mapping of land, ice sheet and glacier topography and vegetation structure through the duration of the mission; (4) observe topography and vegetation structure change through time in selected areas; and (5) achieve 5 m horizontal resolution, 0.1 m vertical precision, and absolute vertical accuracy for ground surface topography including where covered by vegetation. LIST is recommended as a third tiered mission with launch date no earlier than 2018 [1].

As pointed out by the LIST study findings, the instrument required to meet the LIST objectives far exceed those of existing space laser altimeter technologies. In simple terms, an instrument needs to be able to generate a swath width of 5 km, image this swath onto a detector array and produce an image that describes the topography of the sampled area, including through foliage if covered by vegetation, and the 3-D structure of the vegetation cover. An advanced mission concept study for LIST was conducted at GSFC in mid-2007 by the LIST Science Working Group (SWG) which links science objectives and measurement requirements for land topography, vegetation structure, ice sheets and glaciers, and inland water bodies. The results of the study highlight key challenges that are driving factors for any laser altimeter instrument approach used to achieve the mission objectives. The instrument must be capable of: (1) mapping a swath with a width of at least 5 km to acquire global coverage in a reasonable amount of time; (2) ranging accurately to the surface through thin to moderate cloud cover in order to acquire complete coverage in regions that are frequently cloudy; (3) operate with solar background noise to accomplish mapping during both day and night conditions (even for a dawn-dusk sun-synchronous orbit the solar zenith angle is large during parts of the year); (4) large dynamic range to accommodate highly varying apparent reflectance conditions due to changes in surface reflectance, atmospheric transmission and canopy cover; (5) high sensitivity in order to detect returns from the ground through dense vegetation cover; (6) an effective pulse rates of 10 kHz or less for atmospheric profiling and unambiguous surface ranging through clouds; and most importantly (7) highest efficiency in order to minimize required power, mass, size, complexity and cost.

2. AIRBORNE INSTRUMENT DEVELOPMENT

The IIP that is currently underway is to provide the technology growth path for LIST. The airborne instrument concept is shown in **Figure 1(a)**. The laser is based on a high repetition rate Yb:YAG microchip laser as the master oscillator to seed a power amplifier [2]. Link budget analysis has shown that at an altitude of 400 km, energy of $\sim 100 \mu\text{J}$ per pulse per beam will meet science requirements. An average of 5 to 7 return waveforms will be captured to provide the vertical sub-structure information on the sampled area. A realistic goal is to have 10 MOPA lasers, each laser has a beam dividing network such as a diffractive optical element (DOE) [3] to generate 100 beams, this approach will meet the 1000 beam necessary for LIST. The energy per pulse requirement of the MOPA laser before the DOE will be $>10 \text{ mJ}$, at 10 kHz the average optical power is $>100 \text{ Watt}$ per laser. It has been reported, most recently, that Yb:YAG master oscillator power amplifier (MOPA) lasers have demonstrated wall-plug efficiencies of $>15\%$, which makes the prime power for LIST not ideal but manageable since 10 MOPA lasers with 15% wall plug will draw $>6.7 \text{ kW}$ of prime power from the spacecraft.

Another critical enabling technology for next-generation laser altimetry and surface/biomass mapping from space is high sensitivity and low noise avalanche photodiode (APD) detectors. Our IIP baseline detector is an InGaAsP intensified photodiode detector (IPD). The IPD contains a 4×4 anode array of electron sensitive avalanche diode anodes. The expected quantum efficiency at 1030 nm is $>20\%$ [4].

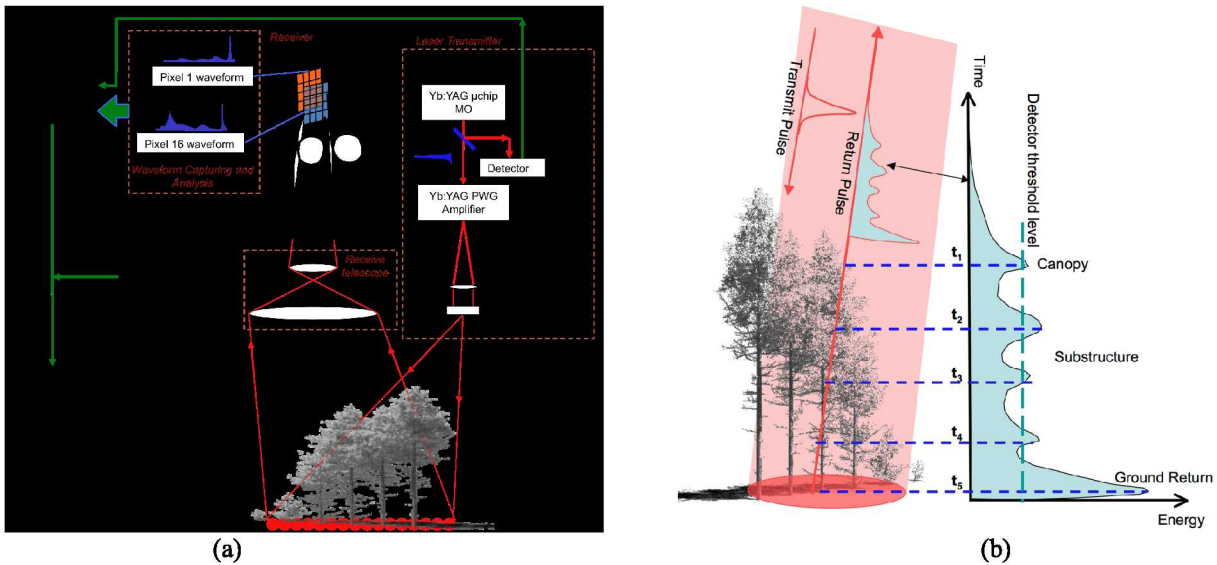


Figure 1. (a) IIP airborne instrument concept; (b) interpretation of time-of-flight information on the return pulse into vegetation heights and ground return.

Data flow management for the airborne instrument will be pushing today's digitizer and data acquisition hardware limit. One of the objectives of the IIP and LIST is to investigate the vegetation canopy and substructure on Earth. To meet this requirement, we will process the return waveform (as shown in **Figure 1(b)**) and extract the substructure information on the sampled area [5]. The laser transmitter in our instrument will be operating at 10 kHz per beam, if we range gate the last $10 \mu\text{s}$ (or 1.5 km) of the return signal into 1 ns bin with an 8-bit digitizer, we will have 100 MB/s data point per beam. In a 16-beam system, there will be 1600 MB/s. In a one hour flight experiment, there will be $>5 \text{ TB}$ of raw data. We can reduce this data set by recording the data at a 25% duty cycle, thus reducing the data set and data rate by a factor of 4. The data rate would then be 400 MB/s and total data accumulated would be $\sim 1.4 \text{ TB}$. We are at this time examining various trades with parameters such range gate width and the data recording duty cycle to finalize a data acquisition system design.

At the end of 2011, we will begin airborne flight tests with this 16-beam instrument. This instrument will be able to

1. demonstrate scalable laser & detector approaches & technologies to meet the LIST mission requirements.
2. demonstrate an airborne swath mapping altimeter measurements using:
 - a. High efficiency, short pulse (< 1 ns) multi-beam laser transmitters;
 - b. Higher sensitivity array detectors, waveform capturing;
 - c. Similar spatial resolution (spot diameters) as LIST.
3. characterize performance of key new components/technologies.
4. demonstrate LIST-type measurements over a variety of surface types, including those of vegetation canopy and substructures.
5. quantify airborne measurements over a range of signal and optical background conditions and compare/scale to space.
6. update the LIST mission design and measurement approach based on the technology evaluations and airborne measurement findings.

Table 1 summarizes the LIST challenges and the IIP risks mitigation approaches.

Table 1. LIST challenges and IIP risk reduction approaches

	LIST Challenges	Demonstrate with IIP	Comments
Number of profiling lines	1000 parallel profiling lines	16 parallel profiling lines	Demonstrate beam division technique
Measurement Rate	Each line measures 5-m ground spots at 1.4 kHz measurement rate	Each line measures 5-m ground spots at 1.4 kHz measurement rate	The airborne demo will oversample by ~35X.
Detection Condition	Detecting ground echoes through tree canopies (5% opening) under clear sky conditions (~70% one way transmission)	Detecting ground echoes through tree canopies (5% opening) under clear sky conditions (~70% one way transmission)	Demonstrate measurement sensitivity and waveform processing to sample canopy substructure
Alignment Sensitivity	Alignment of 1000 transmitters with receiver optics	Alignment of 16 transmitted beam with receiver optics	Retiring the risks of multiple boresight alignment
Data Processing	1000 channel data acquisition, processing, and storage	16 channel data acquisition, processing, and storage	Demonstrate the feasibility of needed data processing
Resources	<7 kW peak electrical power. Assuming 15% laser efficiency. Implies <7W electrical power per profiling line	<0.1 kW peak electrical power. Assuming 15% laser efficiency. Implies <7W electrical power per profiling line	Demonstrate laser efficiency of microchip laser and planar waveguide amplifier architecture
Laser	1000 laser beams with 100 μJ per beam @ 10 kHz; Possible 10 Lasers each with 100 beams	16 laser beams with 100 μJ per beam @ 10 kHz; Also demonstrate 20 pm spectral width.	Demonstrate narrow linewidth laser with power scalable for space
Detector	1000 pixel photon counting array with single photon sensitivity, each pixel with > 1 GHz bandwidth and read out integrated circuit (ROIC) for waveform readout	16 pixel photon counting array with single photon sensitivity, each pixel with > 1 GHz bandwidth and ROIC for waveform readout	Demonstrate state-of-the-art photon counting detector technology

3. CONCLUSIONS

Recent survey of laser scanning systems in airborne lidar systems provided detailed discussion of the new full waveform lidar systems, which forms the basis of the IIP and LIST missions [5]. In this paper we summarized our IIP effort and the technology grow path it provides for the LIST mission.

4. ACKNOWLEDGEMENT

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5. REFERENCES

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