IceSat 2 ATLAS photon-counting receiver - initial on-orbit performance

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ABSTRACT

Photon-counting receivers are deployed on the NASA Ice, Cloud and land Elevation Satellite-2 (ICESat2) Advance Topographic Laser Altimeter System (ATLAS). The ATLAS laser altimeter design has total six ground tracks with three strong and three weak tracks. The strong track has nominally 4 times more laser power than the weak track. The receiver is operated in photon counting mode. There are 16 photon-counting channels for each strong track and 4 photon-counting channels for each weak track. Hamamatsu photomultiplier with a 4x4-array anode was used as photon counting detector. This receiver design has high counting efficiency (>15%) at 532 nm, low dark count rate (<400 counts per second), low jitter (less than 285ps), short dead time (<3 ns), long lifetime under large solar background radiation, radiation harden for space operation, and ruggedized for survives the harsh vibration during the launch. In this paper, we will present the initial on-orbit performance of this photon-counting receiver.

Keywords: Detectors, photon-counting, laser altimeter, ranging, LIDAR

1. INTRODUCTION

Light Detection and Ranging (lidar) has been widely used in space based scientific measurement. Lidar can operate in sounder mode and backscattering mode. In sounder mode, the laser pulse time of flight (TOF) is measured for distance between the lidar instrument and the target to be measured. It is used for measuring surface topography, vegetation mass, sea ice thickness, etc. In backscattering mode, the laser backscattering intensity is measured for the volume properties of the targets. It can be used to measure targets such as cloud and aerosol.

There has been many successful space lidar mission, such as They include laser altimeters such as: the Mars Orbiter Laser Altimeter (MOLA) [D. E. Smith] developed at the National Aeronautic and Space Administration (NASA) Goddard Space Flight Center (GSFC) on the Mars Observer mission in 1992. Lidar In-space Technology Experiment (LITE) [D.M. Winker] developed by NASA’s Langley Research Center (LaRC) was launched in 1994. LITE was an atmosphere backscattering lidar. The Shuttle Laser Altimeter (SLA) [J. Garvin] developed by NASA GSFC. SLA demonstrated laser surface elevation measurements through Earth’s atmosphere and the use of laser altimeter to study vegetation coverage. The Geoscience Laser Altimeter System (GLAS) [James B. Abshire] on the Ice, Cloud and land Elevation Satellite (ICESat) developed at NASA GSFC and launched in January 2003. GLAS had one surface altimetry channel at 1064 nm wavelength and two cloud and aerosol backscattering profile channels. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) [R J Gilbrech] satellite developed by NASA LaRC and Ball Aerospace & Technology Corporation was launched June 2006. CALIPSO lidar measures the atmosphere backscattering profiles. However ICESat2-ATLAS is the first micro pulse photon counting space lidar instrument.

2. PHOTON-COUNTING DETECTOR DESIGN AND PERFORMANCE VERIFICATION

ATLAS of ICESat2 was launched on 15 September 2018. It is the first micro pulse photon counting space lidar instrument. The ATLAS design has total six ground tracks with three strong and three weak tracks (figure 1). The strong track has nominally 4 times more laser power than the weak track. The receiver is operated in photon counting mode.

There are 16 photon-counting channels for each strong track and 4 photon-counting channels for each weak track. Hamamatsu photomultiplier with a 4x4-array anode was used as photon counting detector. In this paper, we will report the initial in space photon counting receiver performances. The science objectives of the mission are “Ice Sheets, Sea Ice, and Vegetation

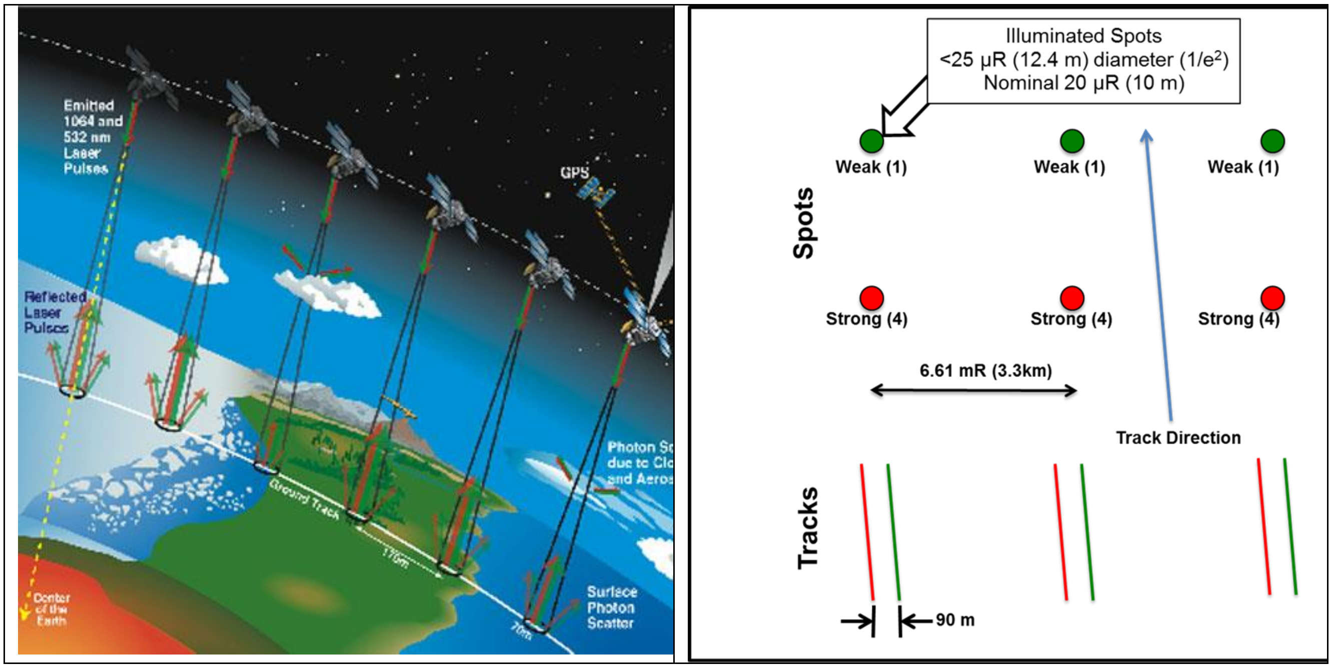

Figure 1. ATLAS orbiting and ground tracks, The Altimeter illuminate ground with 3 strong and 3 weak spots. The strong spot has nominally 4 times optical power than the weak spot. The receiver is operating in photon Counting mode.

The operating at wavelength of ATLAS altimeter is 532nm. For this wavelength, the Hamamatsu R7600-300-M16 Green Extended Cathode PMT was selected for the instrument photon-counting receiver design. The flight module is the ruggedized version. This PMT has 16 individual photon multiplier channels. Two sub-assembles were developed, one has 16 photon counting channels and there other has 4 photon counting channels. For the 4-channel module, 4 original PMT channels are combined with a wired-or to form a single photon counting outputs. The 16 channel version is used for the strong spot and the 4 channel version is used on the weak spot. To reduce the PMT electrical output pulse height induced timing error (jitter), a Constant Fraction Discriminator (CFD) (CFD electrical assembly was design and developed by Fibertek, Inc.) was used to convert the analog PMT output pulse to a digital pulse. This digital pulse is then fed to a time-to-digital converter for the pulse arrival time.

2.1 Receiver performance specifications

ATLAS photon counting receiver requirements are listed in Table 1. It requires high counting efficiency (>15%) at 532 nm, low dark count rate (<400 counts per second), low jitter (less than 285ps), short dead time (<3 ns), long lifetime under large solar background radiation, radiation harden for space operation, and ruggedized for survives the harsh vibration during the launch.

Parameter	Specification		Unit	Meet Spec
	Min	Max		
Jitter (rms)		285	ps	Yes
Wavelength	532		nm	Yes
Count Efficiency	15%			Yes
Dead Time	3.1	3.3	ns	Yes
Max Photon # per pulse		12		Yes
Max solar back ground		20M	Count per second per spot	Yes
Dark count rate		160K	Count per second per spot	Yes
Vibration	10		g-rms	Yes
Mission Lifetime	3.5		year	Yes

Table 1, Photon counting receiver specifications

All of these performance parameters have been verified during the on ground component and I&T (integrating test) level tests. The receiver met all of the performance specification.

In the follow few charts, we will show some test graphs from the test reports.

PMT is a very low noise device. The intrinsic dark count rate is at ~25 CPS (count per second) for each photon multiplier channel (Figure 2). The 16-channel receiver module has 16 individual counting channels, which is marked as channel1 to channel16. The 4-channel receiver module has 4 individual counting channels, which is marked as channelA to channelD. Each module has a lump sum dark count rate of ~400 CPS.

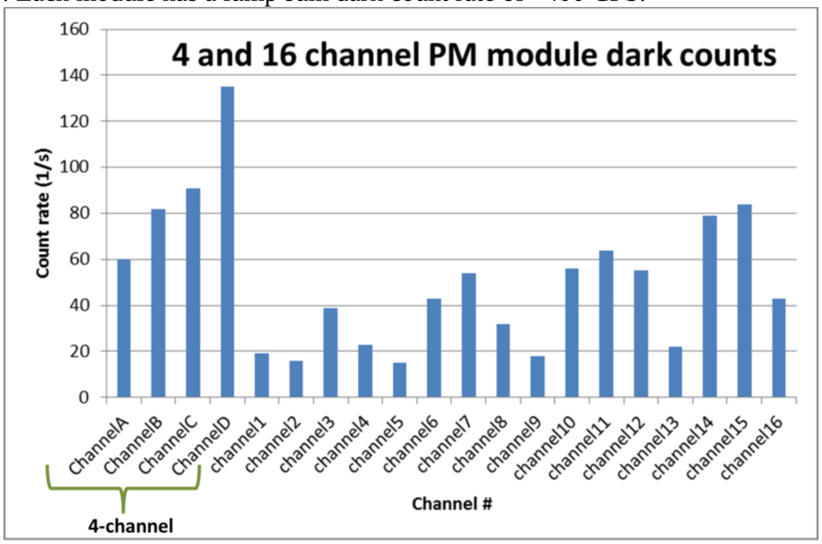

Figure 2. PMT dark count rate. Each PMT tube has 16 individual photon detection channels. Channel1 to channel16 is the performance of 16 channel receiver configuration. ChannelA to channelC is for 4 channel receiver performance, where 4 PMT channels are combined into 1 photon counting channel for weak lidar tracks.

With constant fraction discriminator design, PMT has very low time jitters, as shown in figure 3. Jitter value is less than root-mean-square (rms) value of less than 250 ps.

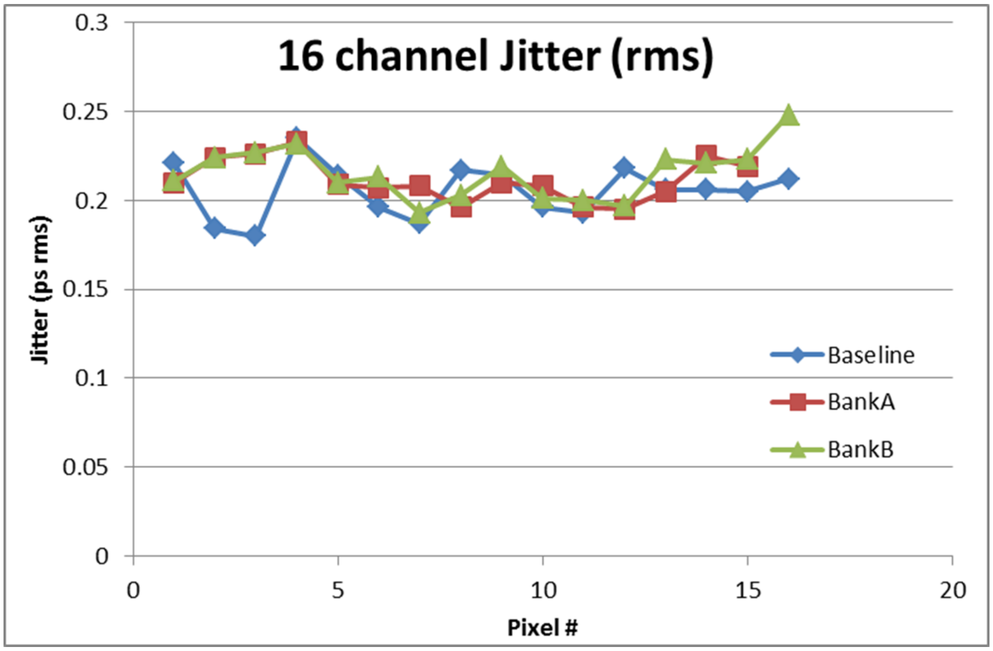

Figure 3 PMT receiver jitter performance for three different receiver assemblies. Baseline, BankA and BankB, the all have jitter less than 250 ps (rms)

Counting linearity was tested during I&T as shown in figure 4. All receivers has linear performance. The illumination stopped at 175,000 counts per second. It has show a very linear performance under this count rate.

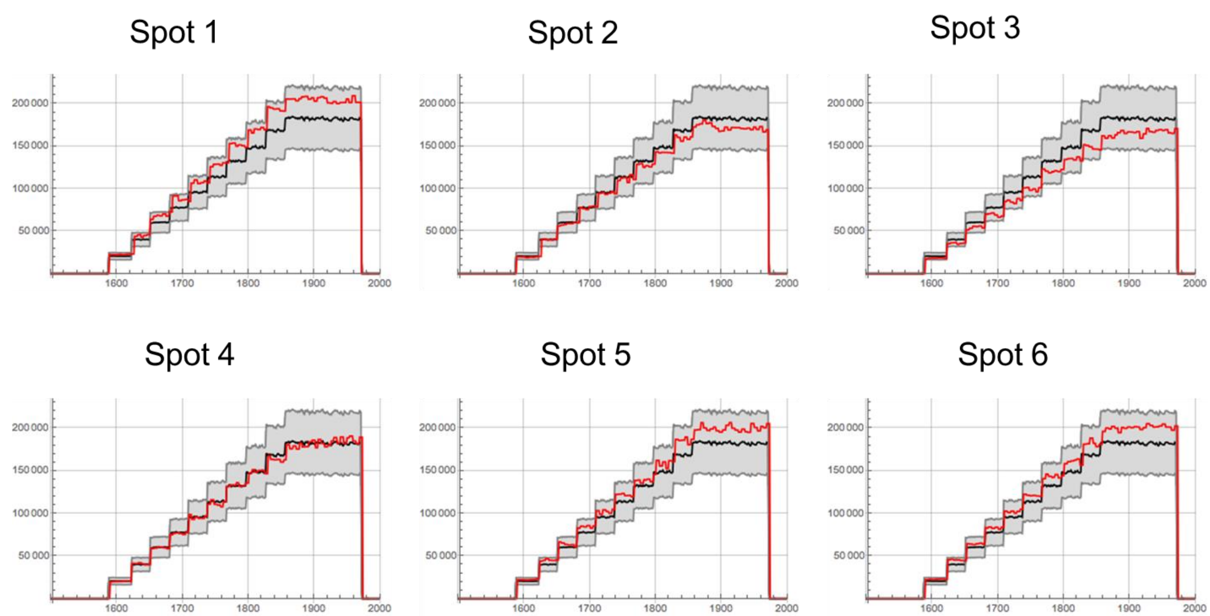

Figure 4, Plots are of return events/shot vs. sample number. Blue is the commanded value – represents the target number of photoelectrons/shot.Black is the expected number of events/shot, based on a deadtime model. Gray is uncertainty, partly from knowledge of the dead time but mostly from our ability to control the input. Red is observed events/shot

3. PHOTON-COUNTING DETECTOR INITIAL ON ORBIT PERFORMANCE

Since the ICESat2-ATLAS launched on 15 September 2018, the instrument is operating exceptionally well. A large amount of data has received. In this section, we will report some of the initial receiver/PMT on orbit performance.

3.1 Dark count rate

As shown in Figure 5, On orbit receiver dark count, x-axis is time in hours, y-axis in per track dark count rate in count per second (CPS). The upper plot has two hours span in time and lower plot has 30 hours span. The count rate over a 2-hour period shown true dark counts at the minimum (~400CPS) (Colors ROYGBV correspond to Spots 1-6), it matches the on ground tested PMT data count rate. The lower plot of long span count rate over 30 hours shown two types of peaks, a high spike over 20,000 CPS, and low humps at order of 800 CPS. After the count rate being plotted as geographic distribution, both low humps and high spikes in the count rate were clearly explained. The lower humps in figure 5 is due to the stray light getting in at high latitudes (figure 6, left). The high spike in figure 5 is due to the South Atlantic Anomaly (figure 6, right), where charged particles induced count rate increase in the receiver. These count rate spikes are still relatively low when comparing with solar background radiation, which will be seen after the door on the telescope opened.

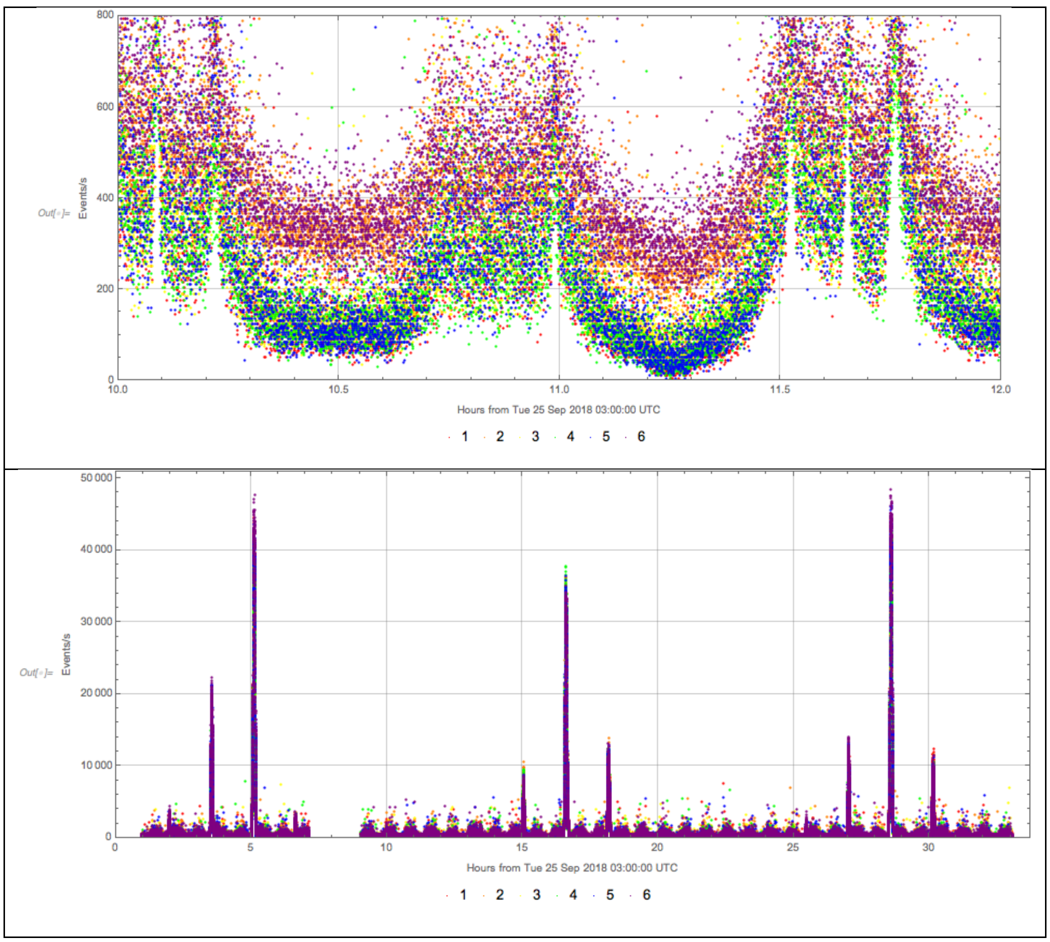

Figure 5, On orbit receiver dark count, x-axis is time in hours, y-axis in per track dark count rate in count per second, upper has two hours span and lower plot has 30 hours span. The count rate over a 2-hour period, showing true dark counts at the minimum (Colors ROYGBV correspond to Spots 1-6), at order of 300 CPS, it match the PMT data count rate. Long span count rate over 30 hours shown two types of peaks, a high spike over 20,000 CPS, and low humps at order of 800 CPS.

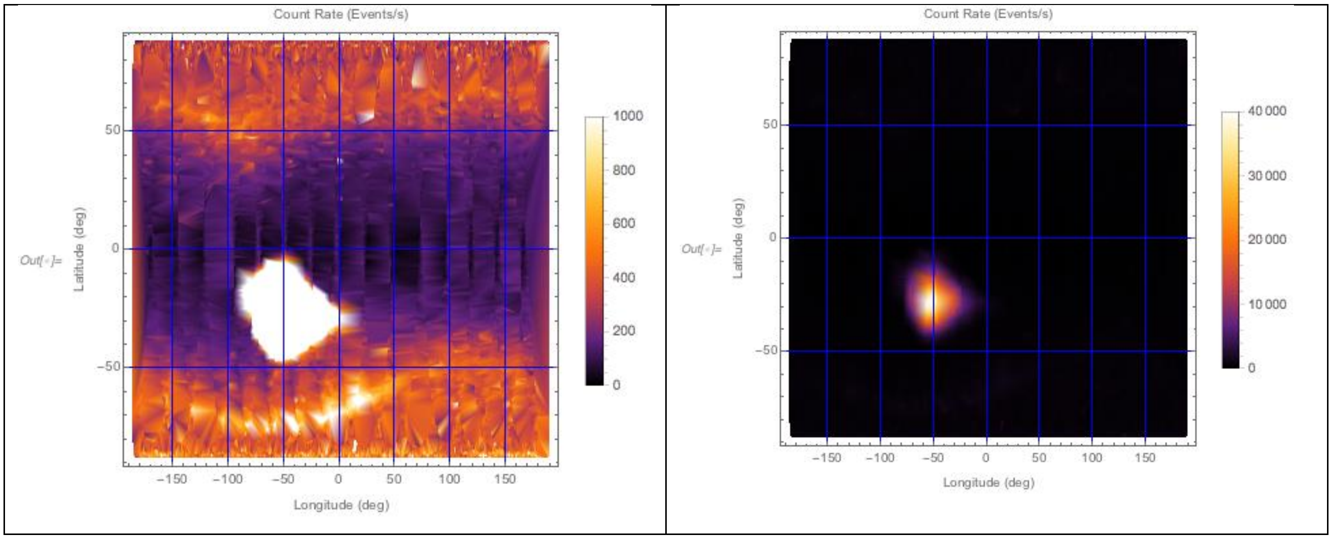

Figure 6. The count rate plot as geographic distribution. The lower humps in figure 5 is due to the stray light getting in at high latitudes. The high spike in figure 5 is due to the South Atlantic Anomaly, where charged particles induced count rate increase in the receiver.

4. SUMMARY

ICESat2-ATLAS multi-channel photon counting detectors have been successfully deployed in the space and operate normal. It has survived satellite launch shock and vibration. The in space receiver performance data are presented and compared with the on ground testing data. The dark count rate in space matches the on ground testing data at the order of ~400 CPS for each spot. Higher dark count rates are also observant

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