International Conference on Space Optics—ICSO 2022

Dubrovnik, Croatia

3–7 October 2022

Edited by Kyriaki Minoglou, Nikos Karafolas, and Bruno Cugny,

ATLID (ATmospheric LIDAR) integration and initial test results on EarthCARE satellite

International Conference on Space Optics — ICSO 2022, edited by Kyriaki Minoglou, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 12777, 127771I · © 2023 ESA and CNES · 0277-786X · doi: 10.1117/12.2689292

ATLID (ATmospheric LIDAR) integration and initial test results on EarthCARE satellite

Haas C.[1*], Belhadj T. [2], Kruse K.-W.[1], de Villèle G. [2], Sauer M. [1], Chassat, F. [2], Corselle, B. [2], Tzeremes G.[3], Pereira do Carmo J. [3], Ghose K. [3], Wallace K.[3]

(1) Airbus Defence And Space GmbH, Friedrichshafen, Germany
(2) Airbus Defence And Space S.A.S, Toulouse, France
(3) European Space Agency, ESA-ESTEC, Keplerlaan 1, 2202 AG Noordwijk, The Netherlands,
*Cornelius.Haas@airbus.com

ABSTRACT

EarthCARE is the 3rd Earth Explorer Core Mission of the European Space Agency (ESA) Living Planet Program, with the fundamental objective of improving understanding of the processes involving clouds, aerosols and radiation in the Earth's atmosphere [2] [3] [5] [6]. EarthCARE data products will be used to improve climate and numerical weather prediction. The data products include vertical profiles of aerosols, liquid water and ice, observations of cloud distribution and vertical motion within clouds, and will allow the retrieval of profiles of atmospheric radiative heating and cooling [4]. For above mission objective, the EarthCARE satellite hosts four complex instruments, the ATLID, (ATmospheric LIDAR from Airbus Toulouse), the CPR (Cloud Profiling Radar, from JAXA/NEC), the MSI (Multi Spectral Imager from SSTL) and the BBR (Broad Band Radiometer from TAS-UK).

The instrument performance verification approach is based on (a) the full performance verification testing done on instrument level, and (b) on Instrument Performance Checks (IPCs) to be repeated periodically on instrument and satellite level. IPCs are designed to confirm that the core instrument performance as verified on instrument level does not degrade after integration on the platform and throughout the overall satellite AIT campaign until launch.

Five ATLID IPCs have been defined in close cooperation between Airbus instrument and satellite prime teams, considering instrument performance verification needs as well as feasibility of IPC repetition in satellite AIT. This feasibility refers mainly to satellite AIT limitations for laser hazard protection measures, cleanliness (ISO8 environment), complexity of optical setups, need for limited test durations<1 day and more difficult instrument accessibility (instrument integrated at more than 3m height on the satellite).

For the ATLID Lidar instrument, the following IPCs have been defined: (1) Transmit Laser Beam Line of Sight (LoS) stability, (2) Activation of Transmit Laser beam steering mechanism, (3) Laser pulse energy knowledge stability, (4) Overall Receive chain optical response check and (5) Detection chain total noise in darkness. IPC test definition as well as test results from instrument level and satellite level IPC testing will be presented. The trend of ATLID IPC test results is found stable along all test repetitions done until today.

Keywords: EarthCARE, ATLID, performance check, detection chain, receive chain, laser pulse energy, laser line of sight

1. INTRODUCTION

1.1 EarthCARE mission and satellite

EarthCARE is the third ESA Earth Explorer Core Mission. It is being implemented in collaboration with the Japan Aerospace Exploration Agency (JAXA), which is providing the Cloud Profiling Radar [9]. The European instruments are the Atmospheric Lidar, the Multi-Spectral Imager (whose status is discussed in a sister paper of the same conference session [10]) and the Broad Band Radiometer. The common platform allows the instruments to collect co-registered observations from all four instruments and allows the instrument data to be processed individually or synergistically [8].

The 2 tons satellite will be placed in a sun-synchronous orbit of around 400 km, with a descending node crossing time of 14:00 and a repeat cycle of 25 days. The mission lifetime is 3 years, with sufficient consumables for a year extension. EarthCARE builds on the success of the Cloudsat/Calipso mission, with improved performance and collocated radiation observations. The crux of the EarthCARE mission is its ability to collect simultaneous, co-registered observations from the four instruments mounted on a common platform. These will measure the vertical structure and horizontal distribution of cloud and aerosol fields, together with the outgoing radiation, over all climate zones. The instruments will operate individually and in synergy, with all fields of view directed towards the satellite ground track. MSI field of view (FOV) covers nadir but is pointed slighted to one side of the ground track, and BBR incorporates additionally a forward and a backward pointing FOV. The scientific objective of the mission is to improve understanding of cloud-aerosol radiation interactions and Earth emitted thermal and reflected solar radiation, so that they can be modelled with better reliability in climate and in numerical weather prediction models [8].

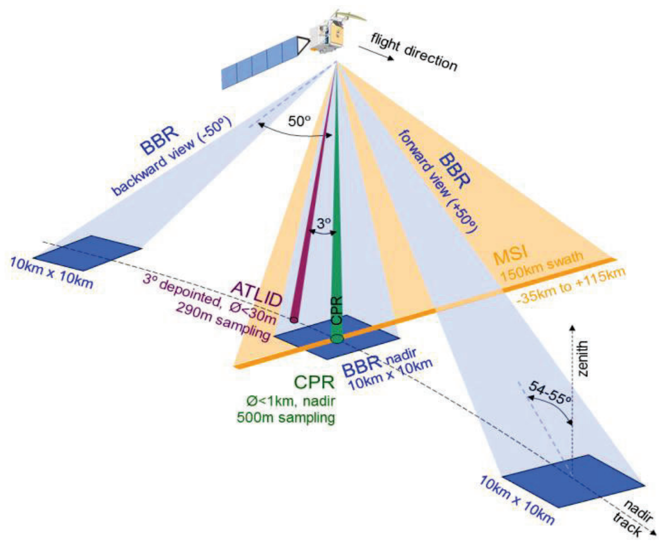

Figure 1: EarthCARE and payload observation geometry

The following Figure 2 (left) shows EarthCARE satellite with all instruments integrated in Airbus Friedrichshafen Cleanroom. It gives an impression of ATLID Instrument protected by closed covers and accessibility inside the platform, at height of approx. 3,5m above floor ground. ATLID PFM instrument has been delivered by Airbus Toulouse to Airbus Friedrichshafen in March 2020 and integrated on the platform in May 2020. The challenging integration by sliding the 550kg instrument in a platform compartment with less than 2cm clearance can be seen in Figure 2 (right). An additional unexpected challenge has been the first Corona lockdown constraints in this period.

Following unexpected failure of ATLID laser electronics in June 2021, the ATLID was dismounted from the platform, for laser electronic repair, and then remounted back on the platform in March 2022. After each ATLID integration on the platform, a set of ATLID IPCs has been executed to confirm unchanged good health and performance of the instrument.

Today (Aug 2022), the EarthCARE satellite is complete and has been transported to the environmental test facility in Noordwijk (ETS). The satellite environmental test campaign will start in October 2022 by satellite vibration and acoustic testing, after completion of some remaining CPR retrofit over the summer period.

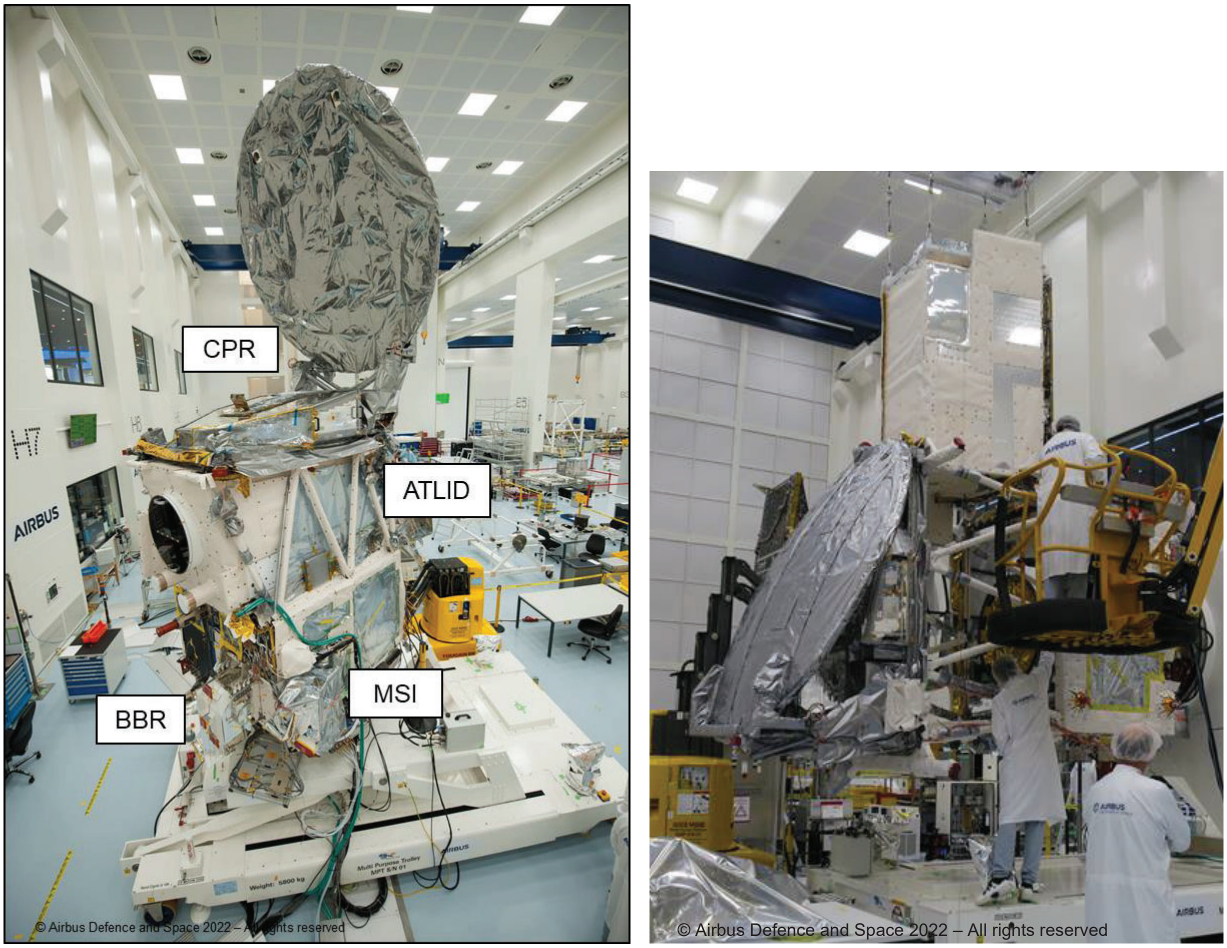

Figure 2. EarthCARE satellite with all instruments integrated, CPR reflector antenna deployed, in Airbus Friedrichshafen cleanroom (left). ATLID integration into the EarthCARE platform (right).

1.2 ATLID instrument

The ATLID instrument is the first UV LIDAR with High Spectral Resolution capability [1]. The Lidar emission in ultraviolet (UV) at 355nm has been chosen because of the higher molecular scattering compared to that from longer wavelength light; enhancing the Rayleigh signal in this manner helps to distinguish between the backscattering from aerosol particles, with monochromatic backscattering (Mie), and the molecular backscattering (Rayleigh) that is spectrally broadened by a few GHz. This distinction allows quantifying the extinction-to-backscatter ratio. The spectral separation is performed via the High Spectral Resolution Etalon (HSRE) included in the telescope focal plane of the instrument. A polarizer optic allows to also quantify the cross polarized backscattered signal, such that it is possible also to distinguish certain aerosol type with oriented shapes.

The double capability of ATLID with its 3 channels (Co-polarized Mie, Co-polarized Rayleigh, Cross-polarized) leads to unique unprecedented LIDAR products. Previous LIDAR in orbit have not yet combined the HSRE capability with the polarization backscattering measurement. The CALIPSO is a LIDAR mission with double wavelength (1064nm and 532nm) and with two polarization sensing but with no UV wavelength and no HSRL capability, and the AEOLUS mission provides indirect backscattering products with Mie and Rayleigh separation but only with one single polarization [1], [11].

The ATLID LIDAR data provides backscattered signals measured with vertical resolution from 100m (0 to 20km) to 500m (20 to 40km); Figure 3. The UV laser power of 35mJ is emitted in 35ns pulses with a pulse repetition frequency (PRF) of 51Hz within a typical 36µrad total emission cone angle. In baseline settings, the backscattered signals are accumulated on MCCD after two laser shots, leading to a ground sampling of 285m from two typical 14m diameter laser footprints. The main performance requirements are assessed with on ground averaging of 10km of these accumulations [1].

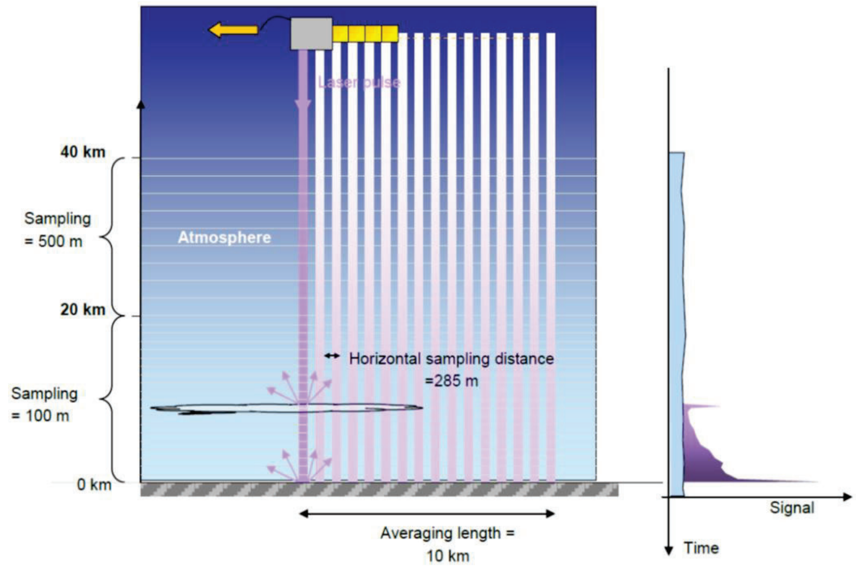

Figure 3. ATLID sampling scheme for vertical range and ground sampling

1.3 ATLID design description

The ATLID instrument is bistatic LIDAR architecture: two independent paths for emission assembly (TxA) and for receiver assembly (RxA); the Figure 4 presents the overview of the design described just below.

The TxA is based on a tripled Nd:YAG diode pumped MOPA (Master Oscillator Power Amplifier) laser developed by Leonardo (*Pomezia*), and an external beam expander (EBEX) developed by Sodern (*Limeil Brévannes*). The laser emission timing is synchronized with the detection chain [1].

The RxA is a 620mm aperture SiC telescope with attached SiC focal plane assembly. The atmospheric echo is filtered from solar background via narrow band filter and via blocking filter limiting the instrument field of view to equivalent 66.5µrad total cone angle. The echo is then entering the HSRE section (developed by RUAG) which extracts cross-polarization signal and spectrally splits the co-polarized signal into two channels: the HSRE Fabry Perot etalon transmitted signal is collected by the particulate backscatter (so called “Mie”) channel, while the reflected signal is collected on the molecular backscatter (“Rayleigh”) channel. Fabry Perot function combined with the backscattered spectrum induces signal spectral cross talk between the channels that is corrected in data processing. The signal is fiber coupled and acquired on a Memory CCD sensor that ensures very low read out noise, while keeping high quantum efficiency [1].

Both RxA and TxA are mounted on a common stable structure assembly that maintains good passive co-alignment performance of their two independent optical paths, while an active co-alignment closed control loop corrects the remaining thermo-elastic line of sight perturbation with a 10min low reaction time. The co-alignment loop commands a beam steering mechanism (BSM) inside the laser in order to co-align the TxA LoS on the RxA LoS. The control loop inputs are based on the centroiding results from a sampled beam on a co-alignment sensor (CAS) placed inside the focal plane [1].

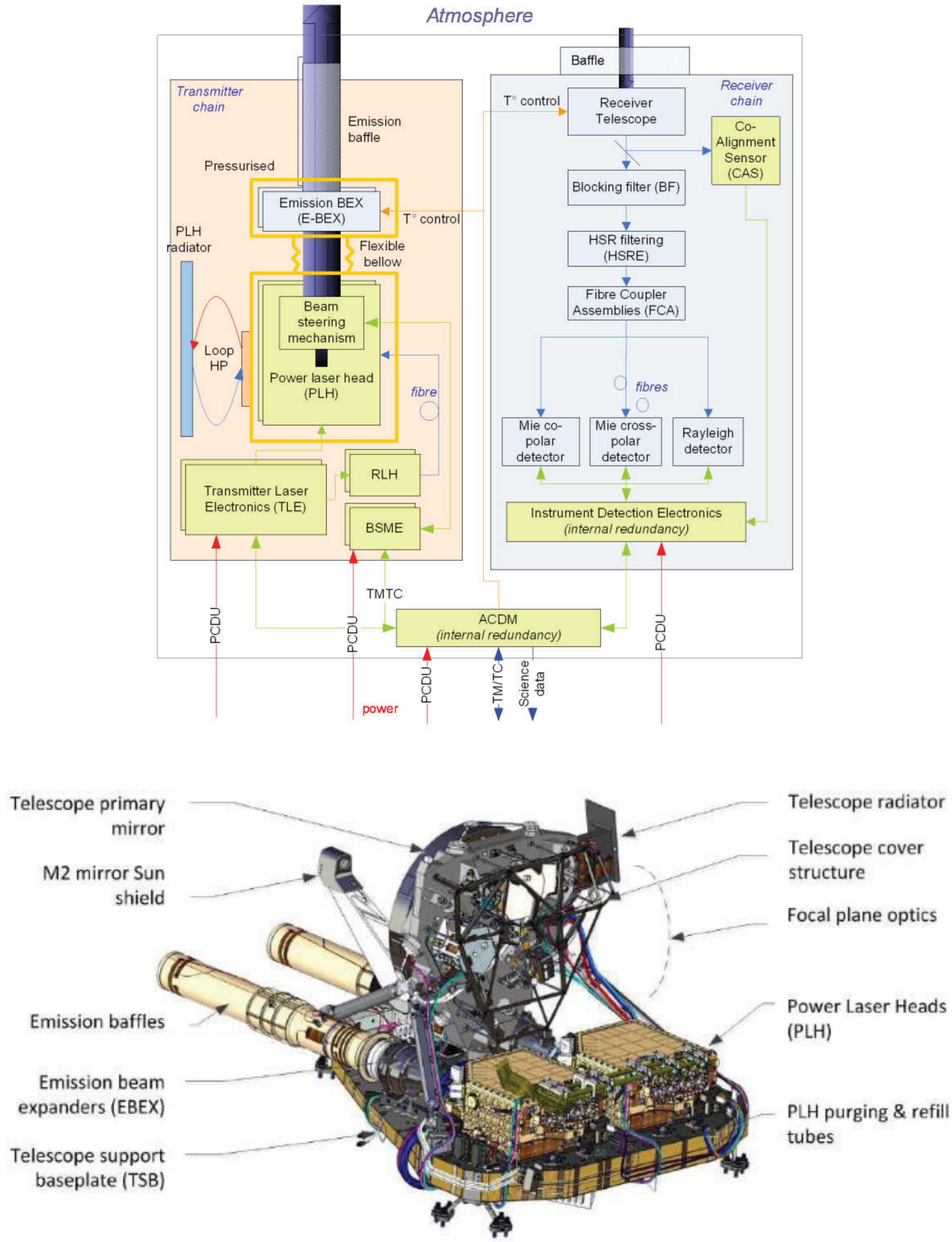

Figure 4. ATLID block diagram description and ATLID Optical Flight Model placed on stable structure assembly

1.4 ATLID Instrument Performance Checks (IPCs) – General aspects and objectives

ATLID PFM has been delivered after completion of all environmental and performance qualification testing on ATLID instrument level (except ATLID radiated EMC qualification, to be achieved by satellite level EMC test campaign). Main ATLID performances have been characterized and the instrument level qualification testing has shown excellent adherence to the ATLID performance specification.

The ATLID LIDAR performance of backscatter absolute retrieval accuracy is based on the relative retrieval accuracy on each channel and the absolute calibration of the LIDAR constant. The Lidar retrieval accuracy shown in Figure 5 is given at 10 km altitude sample, on a 10 km horizontal integration length, for three types of scenes: a sub visible cirrus, a thin cirrus and a depolarization cirrus. Further details on ATLID instrument level performances and test results can be found in [1].

Absolute backscatter retrieval accuracy (10 km altitude, 10 km horizontal integration, β = cloud backscatter coefficient)	**Typical BOL**	**WC at EOL**	**Req.t**
Mie co-polar on sub visible cirrus, β=8 E10^{-7}sr^{-1} m^{-1}	31%	48%	48%
Mie cross-polar on cirrus with 10% depolaristion, β=2.6 E10^{-6}sr^{-1}m^{-1}	19%	23%	45%
Rayleigh above cirrus 10 km	12%	17%	15%
Radiometric stability			
Rayleigh, Mie Cross	0.6%	1%	<5%
Mie Co	0.8%	3%	<2%

Absolute calibration accuracy	**WCEOL**	**Req.t**
Mie co-polar	11.1%	10%
Mie cross-polar	13.1%	15%
Rayleigh	6.6%	10%
Cross talk knowledge		
Spectral in Rayleigh channel	7.9%	<20%
Spectral in Mie co-polar channel	9.6%	<10%
Polarisation in Mie co- or cross-polar channel	1.2%	<1.0%

Figure 5. ATLID LIDAR performance of backscatter absolute retrieval accuracy, based on the relative retrieval accuracy on each channel and the absolute calibration of the LIDAR constant and characterization of the receive channel crosstalks

The following "key contributors" to ATLID Lidar performance have been identified, in order to become subject of five dedicated ATLID IPCs.

- Laser beam line of sight (emission chain, TxA), IPC-1
- Laser beam steering mechanism, IPC-2
- Laser beam pulse energy knowledge (emission chain, TxA), IPC-3
- Receive chain optical response, IPC-4
- Detection chain dark/readout noise (receive chain RxA), IPC-5

The ATLID IPCs are developed by the instrument supplier to be an instrument performance check with "reasonable complexity" for execution also in satellite level AIT (check with possibly reduced accuracy compared with full instrument performance test). ATLID IPC repetition at satellite level within the success criteria shall confirm:

- The ATLID performance to remain unchanged wrt the ATLID instrument level IPC reference data – and implicitly wrt all instrument level full performance verification.
- That qualified instrument performance is not affected by unexpected disturbances caused by the platform and other instruments, neither degraded during satellite environmental testing, e.g due to unexpected ageing.

"Reasonable complexity" of ATLID IPC definition with satellite AIT environment has considered:

- Laser safety: ATLID is classified most dangerous laser class 4. ATLID integration and laser operation in instrument AIT takes place in ISO5 cleanroom environment solely assigned to ATLID, with all AIT team members systematically protected with laser protective glasses. Laser operation in large Satellite AIT cleanroom, with many other projects in the same cleanroom and usually wide visitor gallery, cannot be managed in the same way. IPC definition was required to have ATLID laser setup within an hermetically closed cavity, in order to allow classification of ATLID IPC setup as laser class 1.

- Cleanliness: IPC execution needs to be possible with the closed optical instrument cavity, as Satellite AIT usually has ISO8 environment. All sensitive instrument level performance aspects on open instrument require an ISO5 environment.
- Test duration: IPC execution in satellite AIT shall be feasible within less than one day, in order to allow several satellite level ATLID IPC repetitions with limited impact on satellite schedule critical path.
- Complexity of set-up: ATLID instrument is integrated on the satellite at a height of 3.5m. Each access to the instrument for installation of GSE or for specific measurement is therefore becoming much more complex, compared with instrument AIT and an instrument mounted well accessible on its own trolley.

The following table shows the repetitions of the 5 ATLID IPCs along instrument AIT and satellite AIT.

AIT Level	AIT Phase for IPC	IPC-1: Laser Beam Line of Sight Stability	IPC-2: Activation of Beam Steering Mechanismn	IPC-3: Laser pulse energy knowledge stability	IPC-4 Receive Chain Optical Response Check	IPC-5: Detection chain total noise
ATLID Instrument AIT	Initial Reference	X		X		X
	Post ATLID Acoustic Test	X	X	X		X
	Post ATLID Sine Vibration	X	X	X		X
	Post ATLID TBTV				X	X
	Incoming test in satellite AIT	X	X	X	X	X
EarthCARE Satellite AIT	Post ATLID integration on Platform	X	X		X	X
	Post Laser Electronics Repair	X		X		
	Post satellite mechanical campaign	Nov 22	Nov 22	Nov 22	Nov 22	Nov 22
	During Satellite TBTV Campaign	Jan 23		Jan 23		Jan 23
	Post Satellite EMC campaign	Apr 23	Apr 23	Apr 23	Apr 23	Apr 23
	Launch site	TBC	TBC	TBC	TBC	TBC

Figure 6. ATLID IPC repetitions along instrument and satellite AIT

The next chapter will present in more detail for these 5 ATLID IPCs the IPC objective, required OGSE, measurement principle and measurement steps, evaluation steps, measurement accuracy, IPC success criteria (linked to resulting sensitivity to ATLID Lidar performance), as well as the possible ATLID degradation mechanism that shall be sensed by the IPC.

2. IPC FOR ATLID EMISSION CHAIN

2.1 IPC-1 for ATLID Laser Beam Line of Sight (LoS) stability

Objective of this test is the health check of the coalignment and stability of both nominal and redundant ATLID laser beam lines of sight (TxA Los) wrt receiver line of sight (Rx-Tx coalignment).

The ATLID instrument line of sight is defined by the receive chain (RxA) line of site (LoS), accessible via optical reference alignment cube on the ATLID FPA SiC baseplate, see Figure 7.

The TxA-LoS will be measured wrt to the RxA LoS. For this measurement, a specific TxA IPC OGSE has been designed, that can be mounted on ATLID emission baffles, see Figure 8.

The IPC measurement of the stability of the Laser Beam line of sight (TxA-LoS) consists of 3 measurement steps:

(1) TxA LoS via laser beam spot measurement on a CCD camera array inside TxA IPC OGSE and then,

(2) The TxA IPC OGSE alignment measurement wrt. ATLID RxA reference cube, done by two theodolite measurement and,

(3) The relative TxA IPC OGSE mounting reproducibility wrt ATLID emission baffles exit window, by injection of external LED beam into the TxA IPC OGSE.

The measurement accuracy of the TxA LoS to RxA LoS stability has been determined to be +/-87µrad (quadratic summation of +/-50µrad +for the 2-theodolite measurement of alignment cubes and +/-71µrad for absolute TxA LoS measurement wrt E-Baffle). The success criterion for satellite level IPC for laser beam line of sight stability was defined to be approx. 3 times the measurement accuracy, i.e. +/-230µrad. One notes the ATLID beam steering mechanism capability to re-adjust laser beam line of sight by +/-450µrad in outer space. In addition to the individual measurement accuracy of each ATLID IPC, the actual IPC results are carefully checked for any trend evolution even within above formal test success criterion.

Degradation of the stability of TxA-LoS wrt to the RxA LoS would reveal any mechanical degradation of ATLID TxA – RxA alignment or any physical degradation inside ATLID power laser head, of which the good health is closely linked to the actual TxA beam orientation.

Figure 8 shows more detailed configuration drawing of TxA IPC OGSE and a photo of the actual TxA IPC OGSE.

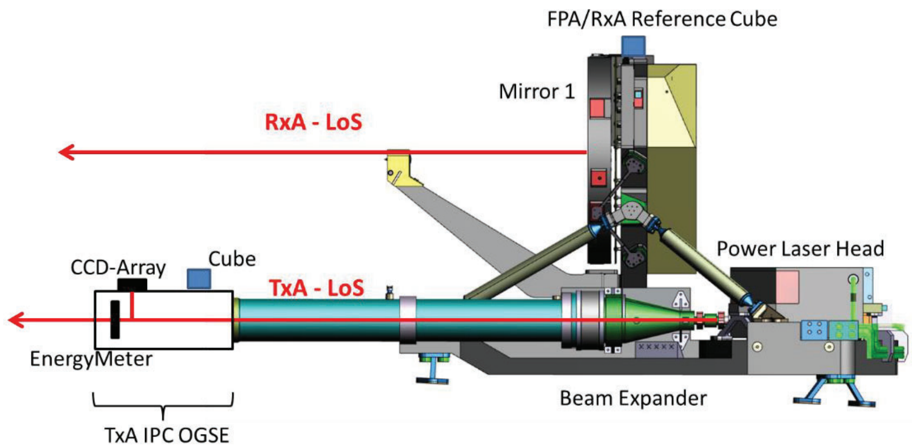

Figure 7 ATLID receive chain RxA line of sight and ATLID laser beam line of sight (TxA – LoS) .

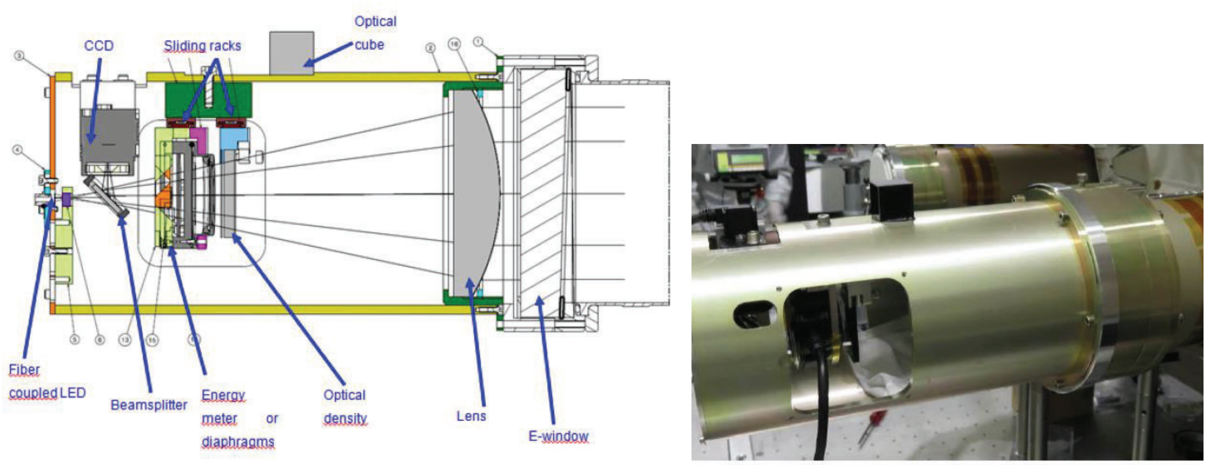

Figure 8. TxA IPC OGSE Design and photo of OGSE mounted on ATLID emission baffle.

Figure 9 gives an impression of the satellite level ATLID Laser Beam Line of Sight (LoS) stability measurement step, by theodolite measurements. Increased complexity due to the height of ATLID position inside the platform is directly visible. With this setup, it is 2 days to complete the IPC for both redundancies, this is the longest ATLID IPC.

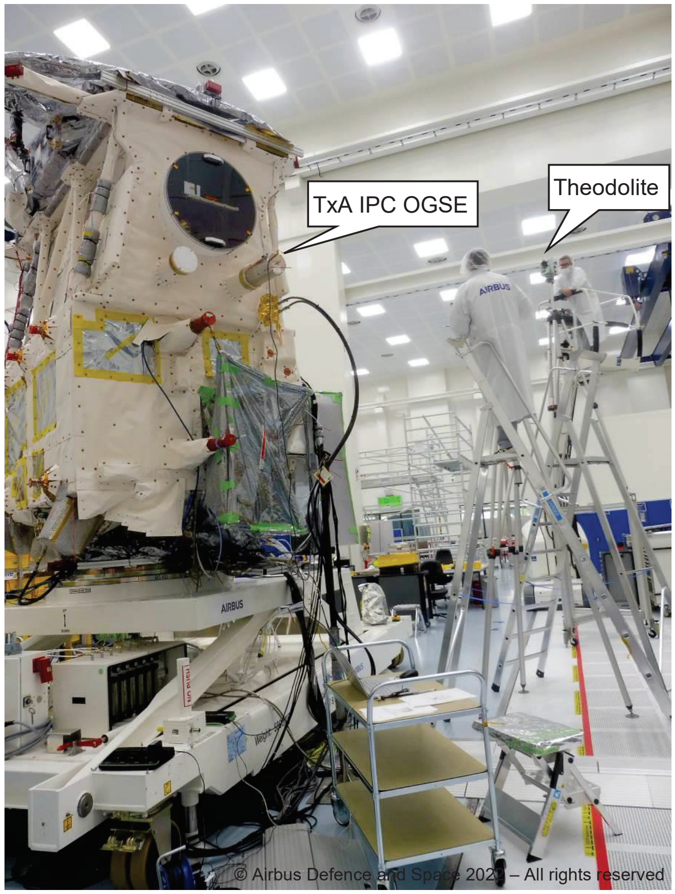

Figure 9. TxA IPC setup for alignment cube measurement with theodolites, installed on tripods at 3,5m height.

Figure 10 shows the available test results, from instrument and satellite level IPC repetitions. One can see the final TxA LoS error calculated from the contributors of:

- Theodolite Measurement of TxA IPC OGSE cube +Z face normal in ATLID reference frame (FPA cube)
- Theodolite Measurement of TxA IPC OGSE cube -Y face normal in ATLID reference frame (FPA cube)
- Measurement of TxA laser beam spot position on TxA IPC OGSE CCD matrix detector
- Measurement of TxA IPC-OGSE external LED centered position on TxA IPC OGSE CCD matrix detector
- Resulting TxA LoS error/stability result calculation, against success criterion of +/-230µrad (radial).

Instrument level tests colored in grey take first instrument level measurement as reference. Satellite level tests colored in orange take last instrument level test (incoming test in satellite AIT) as reference. On B-side, one TxA LoS stability measurement was done on instrument level, after ATLID dismounting for laser electronic repair, and subsequent re-mounting on the platform.

Overall ATLID Laser Beam LoS error are well below the success criterion of +/-230µrad and don't show any apparent trend, hence ATLID good health and unchanged performance can be concluded from this IPC for the related performance aspects.

ATLID A-side Laser Beam LoS error measurements / trend

AIT Phase of IPC	Date	Beam spot on OGSE CCD		OGSE LED fiber beam		+Z cube IPC OGSE			TxA LOS error			-Ycube IPC OGSE		
		Yccd (pixel)	Xccd (pixel)	Yccd (pixel)	Xccd (pixel)	XFPA	YFPA	ZFPA	XFPA (µrad)	YFPA (µrad)	Radial (µrad)	XFPA	YFPA	ZFPA
Initial Reference test	07.06.2019	202,5	1117,8	322,4	1054,1	0,001001	0,000147	0,999999				-0,0006570	0,9999997	-0,0002780
Post acoustic test	26.08.2019	198,6	1120,3	315,5	1054,4	0,001019	0,000188	1,000000	**70**	**31**	**76**	-0,0004050	1,0000000	-0,0001420
Post sinus	06.09.2019	193,3	1117,8	308,9	1047,7	0,000998	0,000221	0,999999	**67**	**20**	**70**	-0,0001645	-1,0000000	0,0003710
Incoming (ref)	04.03.2020	194	1129	312	1060	0,000909	0,000166	1	**0**	**0**	**0**	0,000712	-1	0,000055
Post ATLID Integration	13.10.2020	192	1124	307,4	1059,5	0,000957	0,000155	1,000000	**-57**	**-4**	**57**	0,001131	-1,000000	0,000008
Post Laser Electronics Repair	14.04.2022	152,5	1144,5	232	1098	0,000930	0,000218	1	**-56**	**19**	**59**	0,000865	-1,000000	0,000078

ATLID B-side Laser Beam LoS error measurements / trend

AIT Phase of IPC	Date	Beam spot on OGSE CCD		OGSE LED fiber beam		+Z cube IPC OGSE			TxA LOS error			-Ycube IPC OGSE		
		Yccd (pixel)	Xccd (pixel)	Yccd (pixel)	Xccd (pixel)	XFPA	YFPA	ZFPA	XFPA (µrad)	YFPA (µrad)	Radial (µrad)	XFPA	YFPA	ZFPA
Initial Reference test	29.05.2019	206,4	1140,7	503,9	1071,7	0,000596	0,000045	1,000000				0,000355	-1,000000	-0,000083
Post acoustic test	27.08.2019	202,3	1142	498,7	1068,2	0,000571	0,000042	1,000000	**41**	**-36**	**55**	0,000021	-1,000000	-0,000076
Post sinus	09.09.2019	195,8	1140,8	490,2	1062,2	0,000483	0,000049	1,000000	**-7**	**-78**	**78**	0,001142	-1,000000	-0,000018
Incoming (ref)	05.03.2020	198,7	1152,3	489	1077	0,000425	-0,000006	1,000000	**0**	**0**	**0**	0,000567	-1,000000	-0,000133
Post ATLID Integration	20.10.2020	196	1148	484	1073	0,000468	0,000043	1,000000	**-7**	**44**	**45**	0,001994	-0,999999	-0,000123
Post Laser Electronics Repair	01.03.2022	156	1173	407	1115	0,000387	0,00006	1	**-1**	**29**	**29**	0,00257	-0,999997	-0,000102
Post Laser Electronics Repair	19.04.2022	161,5	1171	419,1	1116,8	0,000393	0,000061	1	**-58**	**18**	**61**	0,001187	-1,000000	-0,000124

Figure 10. ATLID Los error measurement result and trend for measurements in instrument AIT (grey color) and satellite AIT (orange color)

2.2 IPC-2 for Activation of Laser beam steering mechanism

Objective of this IPC is the health check of each PLH beam steering mechanism, as a combined functional and optical check of BSM operation and emission beam displacement.

The Power Laser Head (PLH) includes a Beam-Steering Mechanism (BSM), controlled by BSM electronics (BSME), aiming at adjusting the emission line-of-sight to maintain emission / reception co-alignment in flight (bistatic Lidar design). The full angular range of beam steering function is approx. +/-450µrad in outer space.

The TxA IPC OGSE allows measurement of TxA laser beam spot position on TxA IPC OGSE CCD matrix detector. This beam spot measurement is used for IPC for ATLID Laser beam line of sight (section 2.1), with beam steering mechanism remaining in zero/default position.

The IPC for Activation of Laser beam steering mechanism consists in commanding an angular movement of the BSM and optical measurement of angular displacement of the laser beam, detectable by displacement of laser beam spot on the TxA IPC OGSE. BSM is commanded of 0.1mrad tilt (outer space) displacement on each X and Y axis. Such angular displacement results in beam spot displacement on TxA IPC OGSE of approx. 5 CCD pixels (pixel angular size = 22 µrad, centroid accuracy +/- 0.5 pixel = +/- 11 µrad).

For this IPC, the Laser beam is commanded from zero/default position by 0.67mrad in x-axis direction, then 0.67mrad in y-axis direction and then back to zero/default position. Actual beam angular displacement is calculated from laser beam spot centroid displacement (pixel) on the TxA IPC OGSE CCD detector.

The setup for this IPC with TxA IPC OGSE mounted on ATLID is as above, see Figure 9 (IPC OGSE control and measurements by dedicated software on notebook). Degradation of the beam steering would reveal electrical/mechanical problem of the BSM Piezosystem or control.

IPC Post Integration (ATLID A-Side)	X axis	Y axis
Beam movement measured (urad)	100	111
Beam movement expected (urad)	100	100
Success Criterion	+/-30	+/-30
Status	OK	OK

IPC Post Integration (ATLID B-Side)	X axis	Y axis
Beam movement measured (urad)	98	100
Beam movement expected (urad)	100	100
Success Criterion	+/-30	+/-30
Status	OK	OK

Figure 11. Individual test results for first satellite IPC for activation of Laser Beam Steering mechanism - and optical measurement of laser beam angular displacement (µrad).

ATLID A-Side			
AIT Phase	Date	X Axis	Y Axis
Post acoustic test	26.08.2019	99	99
Post sinus	06.09.2019	99	99
Incoming	04.03.2020	99	99
Post Integration	15.10.2020	100	111

ATLID B-Side			
AIT Phase	Date	X Axis	Y Axis
Post acoustic test	27.08.2019	99	99
Post sinus	09.09.2019	99	99
Incoming	05.03.2020	99	99
Post Integration	21.10.2020	98	100

Figure 12. Trend of test results for IPC for activation of Laser Beam Steering mechanism - in instrument AIT (grey color) and satellite AIT (orange color), measured angular beam displacement in µrad.

ATLID Laser Beam Steering mechanism activations show well reproducible measurements of beam spot displacement on TxA IPC OGSE detector. Results are well below the success criterion of +/30µrad and don't show any apparent trend, hence ATLID good health and unchanged performance can be concluded from this IPC for the related performance aspects.

2.3 IPC-3 for Laser pulse energy knowledge stability

Objective of this test is the health check of emitting paths (TxA/PLH + E-Bex), for detecting any unexpected significant evolution of laser energy due to internal misalignment or contaminations or laser hardware degradation. Laser energy level is set at 35mJ +/-2mJ for ensuring nominal signal detection with satisfactory signal to noise ratio; the laser energy knowledge is needed to ensure radiometric stability performance of the instrument as each LIDAR echo acquisition is corrected from laser energy variation

The IPC for Laser pulse energy knowledge stability consists in parallel ATLID internal/external measurement of ATLID laser beam pulse energy. The ATLID laser pulse energy can be measured by PLH internal photodiode, whilst the external pulse energy measurement is done with TxA IPC OGSE. The TxA IPC OGSE allows measurement of TxA laser beam pulse energy, after installation of a power meter inside the OGSE sliding rack (Figure 9).

The setup for this IPC with TxA IPC OGSE mounted on ATLID is as above, see Figure 9 (IPC OGSE control and measurements by dedicated software on notebook).

Figure 13 shows the IPC results of ATLID laser pulse energy measurement by internal/external photodiodes, well correlated with time. The visible energy oscillations, of approx +/-0.5mJ with 2min period, are nominal behavior and are related to the temperature stabilization/oscillations of laser head internal subsystems.

For the IPC for Laser pulse energy knowledge stability, we take the 5min average of measured pulse energies.

Figure 13 also shows for information further PLH internal photodiode measured laser energies, at the Master Oscillator (IR), amplifier (IR), second harmonic stage (Vis Green), beside the UV pulse energy after third harmonic stage (PD74).

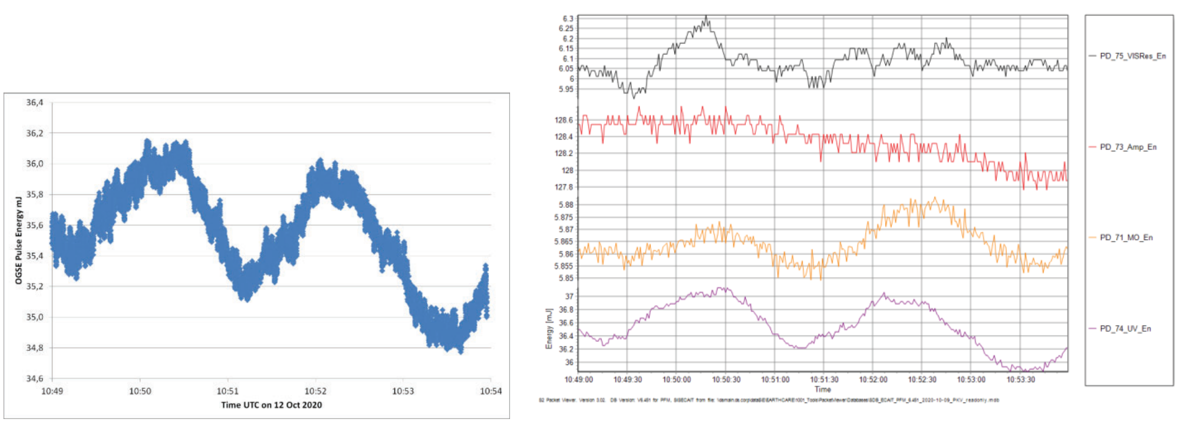

Figure 13: (left) ATLID external OGSE measurement of ATLID laser pulse energy (IPC for Laser pulse energy knowledge stability). (right) ATLID internal measurement of ATLID laser pulse energy (IPC for Laser pulse energy knowledge stability). PLH internal Photodiodes HK-TM for UV pulse energy (PD74). Also shown IR energy of master oscillator MO (PD71), IR energy of Amplifier (PD73) and green visible energy at second harmonic stage (PD75)

The following Figure 14 shows the available measurement results and test evaluation for instrument and satellite level IPC repetitions. One can see the final “energy knowledge absolute stability”, that is calculated from:

- Measured calibrated pulse energy, internal photodiode PD74 (E_PD74)
- Measured pulse energy with external energy meter in TxA IPC OGSE (E_OGSE)
- Energy knowledge calculated as (E_PD74-E_OGSE) / (E_OGSE)
- Energy Knowledge absolute stability calculated as (Energy knowledge calculated – Energy knowledge Initial/Reference).

The accuracy of the measurement has been estimated to +/-7% (driven by OGSE detector calibration and detector thermal sensitivity). Test Success Criterion is +/-10% for the Energy Knowledge absolute stability.

ATLID A-side Laser Pulse Energy measurement/trend

IPC-#	Measurement phase in satellite / instrument AIT	Date	start time	end time	PD74 (raw LSB)	Pulse energy calibrated	Pulse energy OGSE measurement	Energy knowledge	Energy knowledge absolute stability
1	Initial	27. Mai 19	09:05:00	09:09	3060,3	33,98	35,56	**-4,45%**	**Reference**
2	Repeatability	27. Mai 19	15:45:00	15:48	3087,1	34,92	36,54	**-4,44%**	**0,02%**
3	Repeatability	07. Jun 19	09:11:00	09:13	3075,7	34,52	36,42	**-5,22%**	**-0,77%**
4	Post-Acoustic	24. Aug 19	11:40:00	12:12	3096,3	35,24	36,57	**-3,62%**	**0,83%**
5	Post-Acoustic	26. Aug 19	07:48:00	08:14	3076,4	34,54	36,47	**-5,29%**	**-0,83%**
6	Post-sinus	06. Sep 19	17:25:00	17:31	3139,9	36,77	38,34	**-4,10%**	**0,35%**
7	Post-sinus	06. Sep 19	17:34:00	18:01	3131,7	36,48	38,2	**-4,50%**	**-0,05%**
8	Post-sinus	10. Sep 19	12:43:00	13:08	3131,4	36,47	**38,4**	**-5,03%**	**-0,58%**
9	Post-sinus	10. Sep 19	12:34:00	12:39	3159,9	37,47	38,86	**-3,59%**	**0,86%**
10	Incoming	04. Mrz 20	12:47:00	12:52	3092,6	35,11	34,50	**1,77%**	**6,22%**
11	Post Integration	12. Okt 20	10:49:00	10:54	3133,3	36,54	**35,53**	**2,83%**	**7,28%**
12	After Laser Electronics Repair	05. Apr 22	15:04:00	15:09	2994,3	31,67	30,85	**2,64%**	**7,09%**
14	After Laser Electronics Repair	13. Apr 22	14:35	14:40	3040,0	33,27	33,00	**0,81%**	**5,26%**
15	After Laser Electronics Repair	13. Apr 22	15:06	15:21	3030,3	32,93	32,72	**0,63%**	**5,08%**

Figure 14. ATLID A-side Laser Pulse Energy measurement/trend, in instrument AIT (grey color) and satellite AIT (orange color)

Figure 14 and Figure 15 show ATLID A/B-side Laser Pulse Energy measurement/trend. Instrument level tests are colored in grey and take first instrument level measurement as reference. Satellite level test are colored in orange and take same first instrument level test as reference. On B-side, one TxA Laser pulse energy measurement (#13) was done after ATLID dismounting from platform for laser electronics repair, and subsequent re-mounting on the platform.

ATLID B-side Laser Pulse Energy measurement/trend

IPC-#	Measurement phase in satellite / instrument AIT	Date	début	fin	PD74 (LSB)	Pulse energy LND-like Calculated	Pulse energy IPC-50 OGSE measurement	Energy knowledge	Energy knowledge IPC absolute stability
1	Initial	28. Mai 19	11:39	11:44	3290,8	37,09	31,79	**16,67%**	**Reference**
2	Repeatability	28. Mai 19	11:49	11:54	3295,6	37,22	31,91	**16,63%**	**-0,04%**
3	Repeatability	29. Mai 19	09:03	09:13	3302,5	37,41	32,18	**16,25%**	**-0,42%**
4	Repeatability	29. Mai 19	10:25	10:40	3287,9	37,00	31,76	**16,52%**	**-0,15%**
5	Post-Acoustic	26. Aug 19	16:20	16:36	3356,08	38,89	34,34	**13,27%**	**-3,40%**
6	Post-Acoustic	26. Aug 19	16:37	16:27	3357,6	38,93	34,34	**13,38%**	**-3,29%**
7	Post-sinus	09. Sep 19	10:02	10:07	3388,41	39,79	35,02	**13,61%**	**-3,06%**
8	Post-sinus	09. Sep 19	10:11	10:37	3389	39,80	35,01	**13,69%**	**-2,98%**
9	Post-sinus	10. Sep 19	07:48	07:53	3367,6	39,21	34,27	**14,43%**	**-2,24%**
10	Post-sinus	10. Sep 19	07:58	08:03	3354,7	38,85	34,13	**13,84%**	**-2,83%**
11	Incoming	05. Mrz 20	10:12	10:17	3304,60	37,47	32,82	**14,14%**	**-2,53%**
12	Post Integration	22. Okt 20	11:55	12:00	3331	38,20	33,35	**14,54%**	**-2,13%**
13	After Laser Electronics Repair	02-Mar-22	13:20	13:25	3356,89	38,92	34,53	**12,70%**	**-3,97%**
14	After Laser Electronics Repair	12. Apr 22	14:25	14:30	3348	38,67	33,85	**14,24%**	**-2,43%**

Figure 15. ATLID B-side Laser Pulse Energy measurement/trend, in instrument AIT (grey color) and satellite AIT (orange color)

Apparent step of Energy Knowledge absolute stability for ATLID A-side from measurement #9 to #10 is considered nominal behavior, due to specific laser amplifier phasing adjustment, done just before measurement#10, for energy recovery of the laser.

Overall ATLID Laser pulse energy knowledge stability is far better than the success criterion +/-10% and doesn't show any apparent trend, hence ATLID good health and unchanged performance can be concluded from this IPC for the related performance aspects.

3. IPC FOR ATLID RECEIVE CHAIN

3.1 IPC-4 for Receive chain optical response check

The objective of this test is the health check of receiving paths of ATLID and detecting potential unexpected degradation of instrument response, for example due to strong internal misalignments between field-stop and fiber cores or obscuration of optical path e.g due to optics degradation (e.g. for cleanliness issues).

The IPC for Receive chain optical response check consists in illumination of the ATLID telescope aperture by OGSE laser light source, injected into the receive chain by optical fiber mounted on the receive chain (RxA) IPC OGSE cover. (Figure 16).

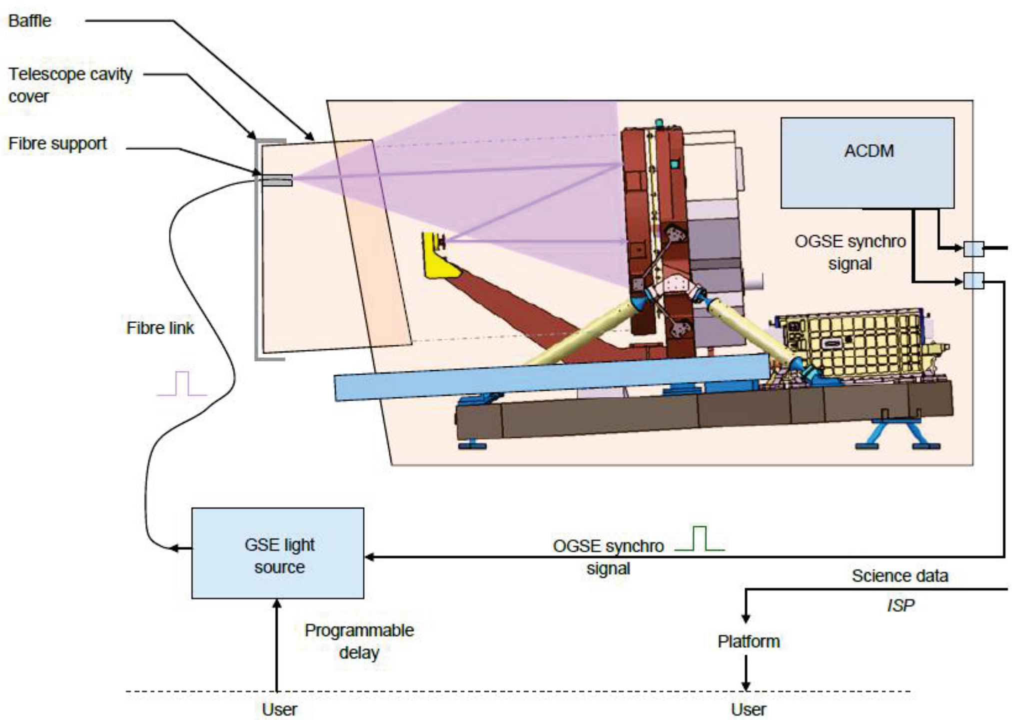

Figure 16: Priciple of IPC-4 for Receive chain optical response check. Receive chain (RxA) illumination by OGSE external laser light source coupled by optical fiber into the receive IPC OGSE cover.

The illumination level at the output of the fiber is controlled through a calibrated photodiode. The distance between the fiber support on the cover and the M1 mirror of the telescope is fixed and repeatable. The angular repeatability of fiber and cover mounting is better than 10mrad with an NA = 0.21 optical fiber in order to limit theoretical angular impact on the coupling efficiency to less than 1%. Roughly $4x10^{-5}$ of the fiber flux is geometrically coupled into 66µrad instrument field-of-view. Acquisitions of the 3 ATLID science channels (Mie-Co, Mie-X, Rayleigh) are then performed at the laser pulse repetition frequency (PRF) rate of 51Hz. Acquisitions of the averaged Coalignment Sensor (CAS) map are performed at the PRF/32 rate (fixed rate at Instrument Detection Electronics output).

The IPC for Receive chain optical response check consists of two measurement steps:

- 5min of acquisition of detection chain signals (lidar, CAS) during illumination by external OGSE laser
- 5min of acquisition of detection chains dark signal (without any external illumination)

For the receive chain IPC measurements, a specific light tight receive chain (RxA) IPC OGSE cover has been designed that can be mounted on ATLID receive/telescope baffle, see Figure 17.

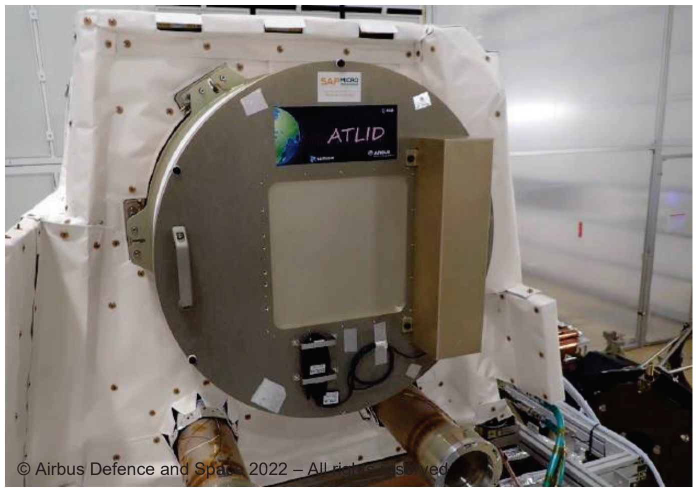

Figure 17: Photo of the receive chain (RxA) IPC OGSE cover mounted on ATLID telescope baffle.

The test evaluation then calculates:

- The sum of the 5min average of all individual Detection Fiber Assembly (Mie-Co, Rayleigh, Mie-X) Lidar acquisitions (LSB counts of 41 low resolution, 212 high resolution, 1 transition sample), each acquisition offset corrected.
- The sum of the 5 min average of all 48 pixel CAS mean echo samples LSB counts over all acquisitions (offset corrected).
- The ratio of above Detection Fiber Assembly LSB sum over OGSE laser power (success criterion +/-30% wrt reference).
- The ratio of above CAS channel LSB sum over OGSE laser power (success criterion +/-30% wrt reference).
- The ratio of "Detection Fiber Assembly over CAS" (success criterion +/-20% wrt reference).

Figure 18 shows measurement/trend results for IPC for receive chain optical response check. Instrument level tests are colored in grey, satellite level tests are colored in orange. Both show the relative response error wrt same instrument level reference (as defined by instrument manufacturer).

IPC-#	Date	AIT Phase	Power OGSE laser (µW)	DFA - Dark	CAS-dark	(DFAs-Dark)/ (OGSE laser)	Rel. Error wrt Instr. Level Ref.	(CAS-Dark)/ (OGSE laser)	Rel. Error wrt Instr. Level Ref.	DFAs/CAS	Rel. Error wrt Instr. Level Ref.
1	05.02.2020	Post TBTV	3,25	73570	349748	22636,92	**5,3%**	107349,54	**9,4%**	0,2109	**-4,0%**
2	05.02.2020	Post TBTV	3,2	67268	320214	21021,25	**-2,2%**	99846,56	**1,8%**	0,2105	**-4,1%**
3	05.02.2020	Post TBTV	3,05	55639	275929	18242,30	**-15,2%**	90180,98	**-8,1%**	0,2023	**-7,9%**
4	05.03.2020	Incoming Test#1	3,025	70729	323413	23381,49	**8,7%**	106754,71	**8,8%**	0,2190	**-0,3%**
5	06.03.2020	Incoming Test#2	3,573	73223	316112	20493,42	**-4,7%**	88404,98	**-9,9%**	0,2318	**5,6%**
		Instrument level References				**21502,80**		**98095,13**		**0,2196**	
6	15.10.2020	Post Intergation	9,094	174407	846883	19178,25	**-10,8%**	93102,71	**-5,1%**	0,2060	**-6,2%**
7	15.10.2020	Post Intergation	3,111	67734	305565	21773,74	**1,3%**	98160,26	**0,1%**	0,2218	**1,0%**

Figure 18. IPC for Receive chain optical response check measurement/trend results, in instrument AIT (grey color) and satellite AIT (orange color)

Figure 19 shows the test setup for the IPC for Receive chain optical response check in satellite AIT. OGSE laser is installed and handled within the protected compartment of black laser protection walls, with receive chain (RxA) IPC OGSE cover mounted on ATLID and connected to the controlling notebook.

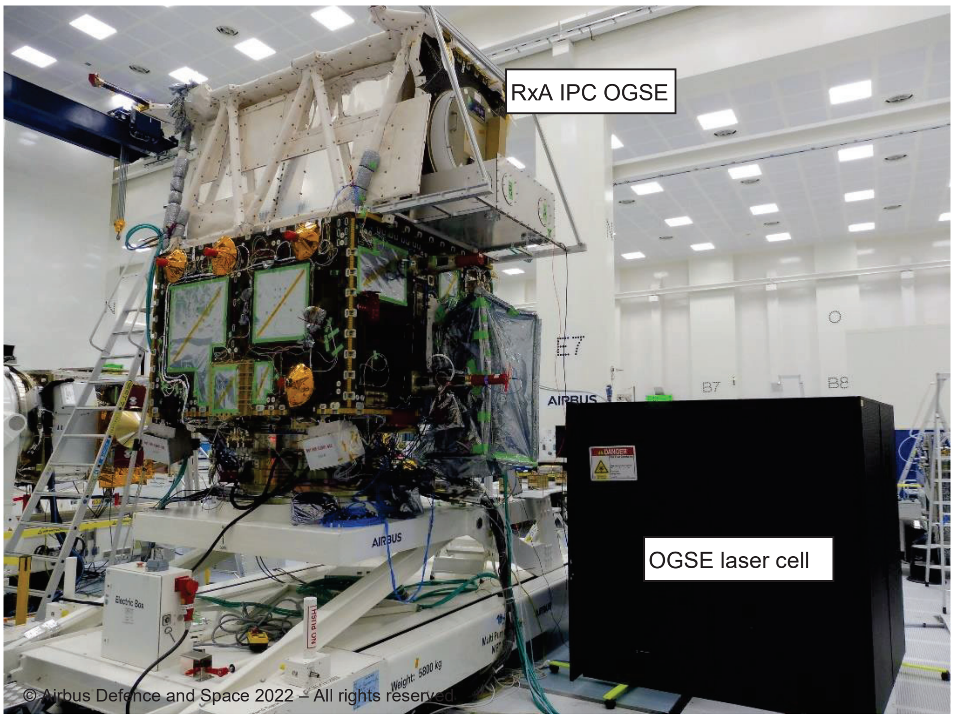

Figure 19. Photo of test setup for the IPC for Receive chain optical response check in satellite AIT.

Overall ATLID receive chain optical response stability is far better than the success criterion +/-20% or +/-30% and doesn't show any apparent trend, hence ATLID good health and unchanged performance can be concluded from this IPC for the related performance aspects.

3.2 IPC-5 for Detection chain total noise in darkness

Objective of this test is the health check of the ATLID detection chain, for any unexpected degradation of detector or detection electronics.

The IPC for Detection chain total noise in darkness consists of measurement of ambient noise figures in darkness, read out noise and DSNU, and comparison with reference data from incoming instrument level reference tests. The read-out noise is a significant contributor to the noise budget and difficult to discriminate from the total noise in darkness. Therefore, specific Readout Noise Calibration mode (RONC) is implemented to limit contribution from other noise sources (such as clock induced charge or dark signal generation with temperature). It consists of reading quasi-empty pixels in order to estimate the read-out stage contribution to the total detection noise.

DSNU will also be recorded in dedicated DCC (Dark Current Calibration mode), but only for information and potential anomaly investigation (no quantitative success criterion).

IPC for Detection chain total noise in darkness uses the same light tight receive chain (RxA) IPC OGSE cover mounted on ATLID receive/telescope baffle, see Figure 15.

The IPC for Detection chain total noise in darkness consists in basically 2 measurement steps:

- 5min Measurement of RONC mode for acquisition of >100 echo profiles.
- 5min Measurement of DCC mode for acquisition of >100 echo profiles.

For the evaluation of all echo profiles, we calculate average (detection offset per sample) and standard deviation (readout noise for each sample) over all acquisitions. Success criteria are defined such that the so called RONC maps (average + standard deviation in LSB) shall not differ more than 20% from instrument level reference values.

IPC average RON (LSB)	ATLID A-side Detection Chain			ATLID B-side Detection Chain		
AIT Phase	MIE	RAY	CROSS	MIE	RAY	CROSS
1-Initial mechanical test	-0,69	-0,76	-2,92			
2-Intermediate mechanical test				-0,79	-0,81	-3,09
3-Final mechanical test	-0,79	-0,71	-2,93	-0,75	-0,81	-3,04
4-Initial TVac test	-0,8	-0,76	-3,08	-0,76	-0,83	-3,04
5-Final TVac test	-0,84	-0,8	-2,97	-0,77	-0,77	-3,03
6-Incoming test	-0,79	-0,76	-3,04	-0,74	-0,86	-3,1
7-Post Integration	-0,86	-0,83	-3,05	-0,81	-0,85	-3,08
Relative difference wrt Incoming	8,9%	9,2%	0,3%	9,5%	-1,2%	-0,6%

Figure 20. IPC for Detection chain total noise in darkness measurement/trend results – ATLID A- and B-side detection chain average of readout noise (LSB) for 3 science channels, in instrument AIT (grey color) and satellite AIT (orange color)

IPC Std Dev RON (LSB)	ATLID A-side Detection Chain			ATLID B-side Detection Chain		
AIT Phase	MIE	RAY	CROSS	MIE	RAY	CROSS
1-Initial mechanical test	5,2	4,88	4,46			
2-Intermediate mechanical test				4,99	4,83	4,47
3-Final mechanical test	5,18	4,89	4,45	5,25	4,89	4,51
4-Initial TVac test	5,29	4,98	4,54	5,35	4,98	4,58
5-Final TVac test	5,24	4,93	4,52	5,26	4,92	4,55
6-Incoming test	5,19	4,89	4,47	5,23	4,89	4,51
7-Post Integration	5,06	4,77	4,37	5,09	4,76	4,41
Relative difference wrt Incoming	-2,5%	-2,5%	-2,2%	-2,7%	-2,7%	-2,2%

Figure 21. IPC for Detection chain total noise in darkness measurement/trend results – ATLID A- and B-side detection chain standard deviation of readout noise (LSB) for 3 science channels, in instrument AIT (grey color) and satellite AIT (orange color)

Above Figure 20 and Figure 21 show the available test results, from instrument and satellite level IPC repetitions. Overall ATLID Detection chain read out noise in darkness is far better than the success criterion +/-20% and doesn't show any apparent trend, hence ATLID good health and unchanged performance can be concluded from this IPC for the related performance aspects.

4. EARTHCARE NEXT STEPS

With the arrival of EarthCARE satellite at the environmental test facility mid-June 2022, and completion of the last outstanding retrofit activity (CPR high power transmitter) until end of August 2022, the satellite will be ready for the satellite environmental test campaign. This campaign will consist of mechanical qualification testing (sine vibration, acoustic, shock) planned for October 2022, thermal vacuum testing planned for January 2023 and the radiated EMC qualification in March 2023, all at ETS facility in Noordwijk.

The good health of the satellite and instruments before the mechanical qualification has been demonstrated by successful platform and instrument functional testing, as well as instruments' individual IPCs for all 4 EarthCARE instruments. After the satellite mechanical qualification, instrument unchanged good health will be verified by another run of instrument IPCs, planned as parallel IPCs. A specific set of instrument IPCs is planned for execution during satellite TBTV, with all instrument detection chain temperatures at flight representative levels. Last round of individual instrument IPCs is then planned after satellite and ATLID radiated EMC qualification, for demonstrating unchanged good health before leaving for the launch campaign.

EarthCARE project is particularly suffering from the Ukraine crisis, as the planned Soyuz launcher is no more available, since withdrawal of Russian Soyuz team from Arianespace launch site in Kourou. The need for finding a new launcher in "last minute" situation is a particular challenge for the Agency, as well as for the industry teams, in order to define in best possible way the mechanical qualification campaign within fixed test facility booking schedule.

At current status (July 2022), there is increasing confidence that EarthCARE launch could become possible early 2024. The Agency is strongly supported towards this objective by high pressure of the ACEO (Advisory Committee for Earth Observation) based on a wide variety of user inputs. In view of the climate crisis and its social urgency, ACEO concludes that the EarthCARE observations are needed without further delay, for extension of the Cloudsat and CALIPSO data sets and maintaining the data gap as small as possible.

5. CONCLUSIONS

The close cooperation between satellite prime and ATLID instrument prime team along all instrument development phases allowed early definition of ATLID instrument performance checks, consequently derived from formal instrument performance tests. First ATLID IPC executions at satellite level did complete the training of the satellite team to operate the ATLID instrument and to control its health check in place of instrument supplier team, without having to face the instrument complexity. Operating and procedure handling have been well established and allowed smooth operation of the instrument and laser, all along the satellite level AIT tests. This is a good asset and good lesson learnt for next LIDAR programs.

Until today, these ATLID IPCs have already been repeated several times and demonstrated ATLID instrument unchanged good health and performance, after integration on the EarthCARE platform. A large set of ATLID level IPC reference test results is available today that will serve as reference for future satellite level ATLID IPC repetitions. ATLID instrument IPCs are evaluated wrt the individual IPC success criteria and also for any apparent trend that might become visible within the success criteria.

A similar IPC approach is available for all other EarthCARE payloads and will be repeated along the upcoming EarthCARE environmental test campaign [10]. Payload IPC trend results will also serve as on ground reference for continuation of related trend investigation during EarthCARE payload in orbit commissioning.

REFERENCES

[1] de Villele G., Pereira do Carmo J., Wallace K., Corselle B., Belhadj T, Bravetti P, Lefebvre A, Chassat F. Kanitz T, Ghose K, Haas C, ESA Atmospheric LIDAR (ATLID) Testing, Qualification and Calibration, ICSO 2020/2021.

[2] EarthCARE—Clouds, Aerosols and Radiation Explorer. Available online: http://esamultimedia.esa.int/docs/SP_1279_1_EarthCARE.pdf

[3] Wallace K, Georgios Tzeremes, Kaustav Ghose, Michael Eisinger, Dirk Bernaerts, Tobias Wehr: European Payload on EarthCARE ESA's Earth, Clouds, Aerosols and Radiation Explorer; Living Planet Symposium 26 May 2022

[4] S. Rusli, R. Koopman, M. Fielding, M. Janisková, T. Wehr, K. Wallace, M. Eisinger, D. Schüttemeyer, J. von Bismarck, C. Retscher, H. Baars, E. Marinou, N. Clerbaux, A. Velazquez Blazquez, D. Bernaerts, B. Frommknecht: ESA Validation and Applications Preparation; Living Planet Symposium 26 May 2022

[5] D. Bernaerts, K. Wallace, M. Rezazad, M. Gollor, C. Soulez-Lariviere, T.Wehr: EarthCARE Mission Status: Overview, Mission Objectives and Requirements, Living Planet Symposium 26 May 2022

[6] Hélière, A.; Wallace, K.; Carmo, J.P.D.; Lefebvre, A.; Eisinger, M.; Wehr, T. A Development status of the EarthCARE Mission and its atmospheric Lidar. In Earth Observing Systems XXI; International Society for Optics and Photonics: Bellingham, WA, USA, 2016; Volume 9972.

[7] Pereira do Carmo, J.; Wallace, K.; Lefebvre, A. Flight LIDAR development and qualification for the ESA Earth Cloud Aerosol and radiation explorer (EarthCARE) mission. In Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2020, Waikoloa, HI, USA, 19–24 July 2020.

[8] Wallace, K.; Hélière, A.; Lefebvre, A.; Eisinger, M.; Wehr, T. Status of ESA's EarthCARE mission, passive instruments payload, In Earth Observing Systems XXI; International Society for Optics and Photonics: Bellingham, WA, USA, 2016; Volume 9972.

[9] Tomiyama, N.; Tomita, E.; Furukawa, K.; Nakatsuka, H.; Seki, Y.; Aida, Y.; Okada, K.; Maruyama, K.; Ishii, Y.; Ohno, Y.; et al. EarthCARE/CPR development status and performance. In Remote Sesning of Clouds and Atmosphere XXV; International Society for Optics and Photonics: Bellingham, WA, USA, 2020; Volume 11531.

[10] Zimmermann L.1, Kruse K.-W, Canas T., Ghose K., Wallace K., Haas C., Sauer M., MSI (Multi Spectral Imager) performance check at integrated EarthCARE satellite system, ICSO 2022

[11] Straume, Anne & Elfving, Anders & Wernham, Denny & Bruin, Frank & Kanitz, Thomas & Schuettemeyer, Dirk & Bismarck, Jonas & Buscaglione, Fabio & Lecrenier, O. & McGoldrick, Phil. (2018). ESA's spaceborne lidar mission ADM-Aeolus; project status and preparations for launch. EPJ Web of Conferences. 176. 04007. 10.1051/epjconf/201817604007