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TECHNOLOGIES FOR ATMOSPHERIC LIDAR (ATLID)

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RESUME - Le Lidar Atmosphérique (ATLID) a été étudié et ses technologies critiques développées pour l'Agence Spatiale Européenne (ESA). Ce lidar fait partie de la charge utile du satellite Earth Radiation Mission du programme Explorer envisagé par l'ESA. Ce satellite sera dédié à l'étude du bilan radiatif terrestre pour des applications climatologiques. Les technologies critiques relatives à ce type de lidar ont été validées sous la forme de maquettes en forme soumises à des tests de performances et d'environement. Les équipements réalisés incluent le laser (Nd-YAG pompé par diodes), son alimentation et son système de controle thermique (boucle diphasique), la chaine de détection avec photodiode à avalanche, le filtre spectral étroit (Fabry-Pérot), le mécanisme de balayage, et le miroir alégé du télescope (diamètre 60 cm). Les résultats satisfaisants obtenus ont permis de consolider le concept et les performances instrument.

ABSTRACT - *The Atmospheric Lidar (ATLID) is the backscatter lidar instrument studied and developed for the European Space Agency (ESA). This lidar is part of the payload for the ESA Earth Radiation Explorer satellite. Elegant breadboard models have been realised and submitted to performance and environmental tests. The laser transmitter, the laser thermal control subsystem (capillary-pumped two-phase loop), the diode laser power supply, the avalanche photodiode detection chain, the narrow-band filter, the scan mechanism, and the telescope lightweight primary mirror have been breadboarded. The instrument design and performances have also been consolidated with regards to the successful hardware results.*

1. INTRODUCTION

The Atmospheric Lidar (ATLID) is a backscatter lidar to be mounted on an ESA Earth Explorer satellite. A comprehensive pre-development work[1] has been performed on this instrument. This covered both the elaboration of an instrument concept and the breadboarding of the most critical elements.

The first part of this work was related to the selection of the instrument concept[2]. Particular care was devoted to the choice of key technologies as well as the optimisation of the concept with regards to the interface requirements. This aspect was mandatory in order to provide the instrument compatibility with a multi-payload mission on existing European platforms (Spot bus, typically).

A breadboarding plan for critical technologies was then issued. The following items were chosen for pre-development: Detection Chain, Laser Head Thermal Control, Laser Head Power Supply, Filters & Coatings, Scan Mechanism, and Telescope mirror. Representativity with regards to the flight hardware was also a major goal, both for performances and major interfaces. Environmental tests have always been performed when relevant or necessary. The breadboard results, as well as the instrument design and performances, are presented hereafter.

2. MISSION AND PERFORMANCE SUMMARY

ATLID will provide useful informations on the atmosphere. being of prime interest for climatology and meteorology. The instrument will retrieve tri-dimensional atmospheric parameters on clouds and aerosols, by measuring the backscattered light from a laser pulse : the altitude and optical depth of the atmosphere is derived from the received signal sampling and datation. The atmospheric objects to be measured include all types of clouds and Planetary Boundary Layer (PBL) aerosols. In addition. the instrument receives the ground echo and the solar flux being scattered on Earth (figure 1).

The cloud measurements occur at a typical 0-10 km range. but the instrument capability goes up to 20 km. They provide cloud top height / mapping for all type of clouds, and extent / optical depth for thin clouds (cirrus). The PBL measurements are performed at a low altitude (0-2 Km typical). They yield PBL top height and optical depth.

The scan motion provides a 700 Km wide swath width, where the laser shots are spread. Measurements can be averaged on a pre-defined area (figure 2). in order to enhance the Signal-to-Noise Ratio (SNR). The radiometric performance have been computed on the basis of a reference atmosphere model eleborated for ESA by scientists. and cross-checked with real data. The selected instrument design satisfies most measurement specifications with a reasonable signal-to-noise ratio margin (table 1). Daytime performance on cirrus clouds is marginal due to the background from scattered sun light. These observations require averaging over larger areas because of the faint backscattered signal being received.

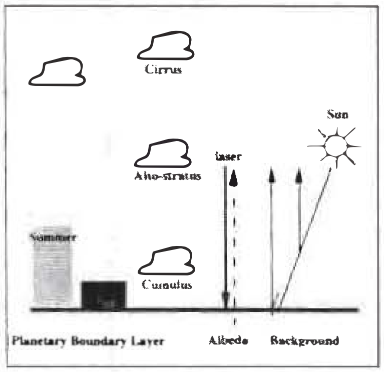

Figure 1 : Measured atmospheric objects

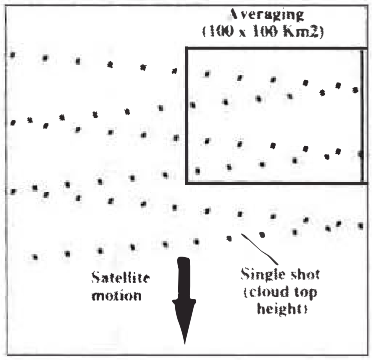

Figure 2: Averaging of measurements

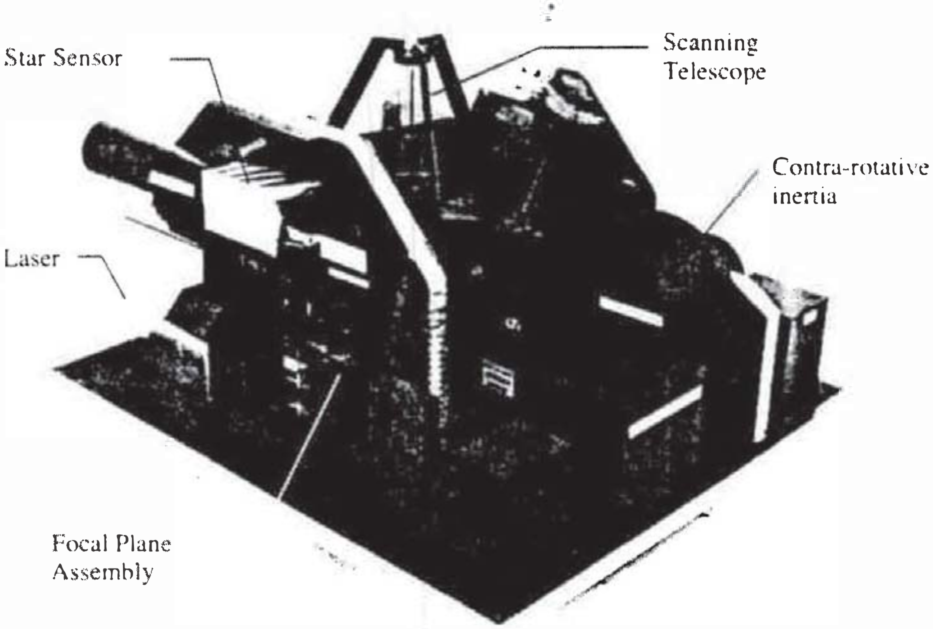

Figure 3 : ATLID instrument lay-out

Laser (diode pumped Nd-YAG)		
Wavelength	1. 064 mm	
Pulse energy / repetition rate	100 mJ / 100 Hz	
Receiver		
Diameter	0.6 m	
Telescope	Cassegrain / scanning	
Focal Plane		
Optics	2 polarization chains Fabry-Perot narrow-band filter	
Detector	Avalanche photodiodes	
Scanning		
Rotation axis	Roll axis	
Scan width	700 Km (+/- 23.5°)	
Scan pattern	Sinusoidal	
Thermal control		
Laser	Two-phase fluid loop (capillary pumped)	
Optics / structure	Passive	
Orbit	Heliosynchronous	
Mean height	800 Km (Polar Platform)	
Budgets	Mass	260 Kg incl. 10% contingency
	Power	500 W at end-of-life
	Size	1.6m x1.3m x1.1m
	Data rate	1 Mbit/s

Table 2 : ATLID major characteristics

4. TRANSMITTER LASER

The transmitter laser is a diode-pumped Nd-YAG laser, with a pulse energy of 100 mJ at l=1.06 mm and a pulse repetition frequency of 100 Hz. The laser is Q-switched with a Pockels cell. The design is based on a zig-zag Nd-YAG slab which is side-pumped by 8 diode stacks of 420 W each (quasi-CW diodes). The stacks are conductively cooled through a metallic cold plate (the laser thermal control system sets the cold plate temperature). The pump unit (stacks and slab) is inserted within a folded unstable resonator. The laser cavity delivers a near diffraction-limited beam (M^2=1.5) by means of a supergaussian reflectivity output coupler. An external beam expander allows to obtain the required divergence (140 µrad). The wall-plug efficiency has been measured to 6.5% on the breadboarded laser head demonstrator (fig. 4). This demonstrator has been developped in an earlier phase on Atlid requirements and submitted to vibration and thermal tests.

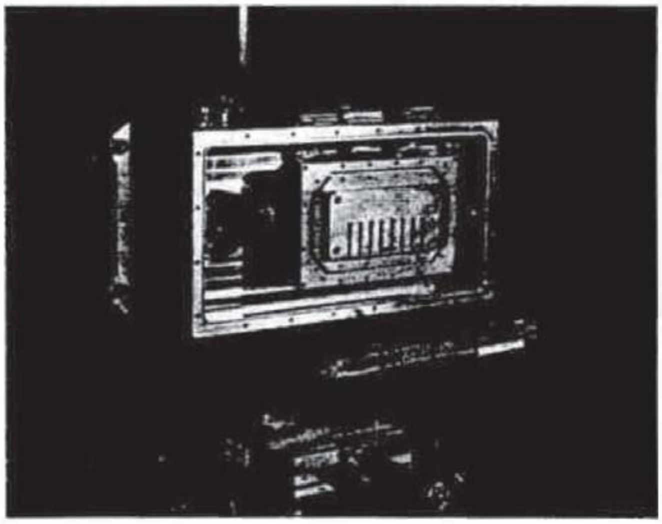

Figure 4 : Laser head breadboard

The Laser Head Thermal Control (LHTC) is a two-phase fluid loop with a capillary pump. A cold plate is attached to the laser head thermal interface. Ammonia is evaporated in the cold plate and condensed again in two radiators. A control reservoir, attached to the cold plate, controls the loop evaporating pressure (hence temperature) by means of a heater (figure 5). The loop is optimised to evacuate the high dissipation of the laser head (220 W at end-of-life) as well as ensuring a high temperature stability (better than +/-1 K). In order to optimize the efficiency, the temperature (and hence the emission wavelength) of the diodes is accurately controlled around 5 °C by means of a cold plate interface.A breadboard has been developped including a laser diode heat simulator, the complete fluid loop, and the two radiators (figure 6). The breadboard has been successfully submitted to vibration tests and thermal vacuum tests. The thermal test results showed excellent performances with regards to the laser thermal requirements, with high margins. The LHTC system operation has also been tested with success for one failed diode stack and for a very asymmetric environment, showing excellent robustness.

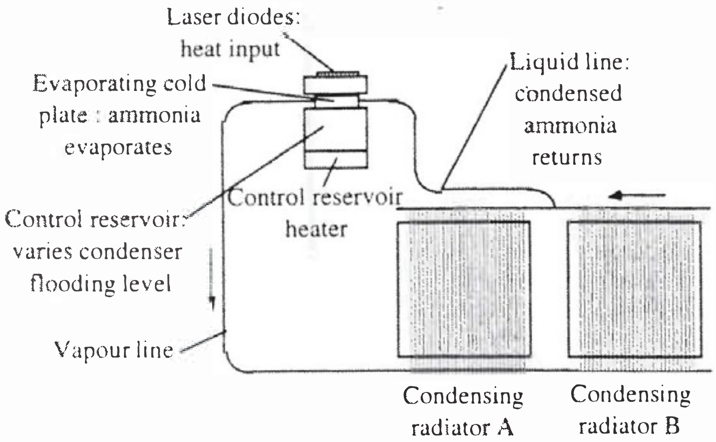

Figure 5 : Laser head thermal control principle

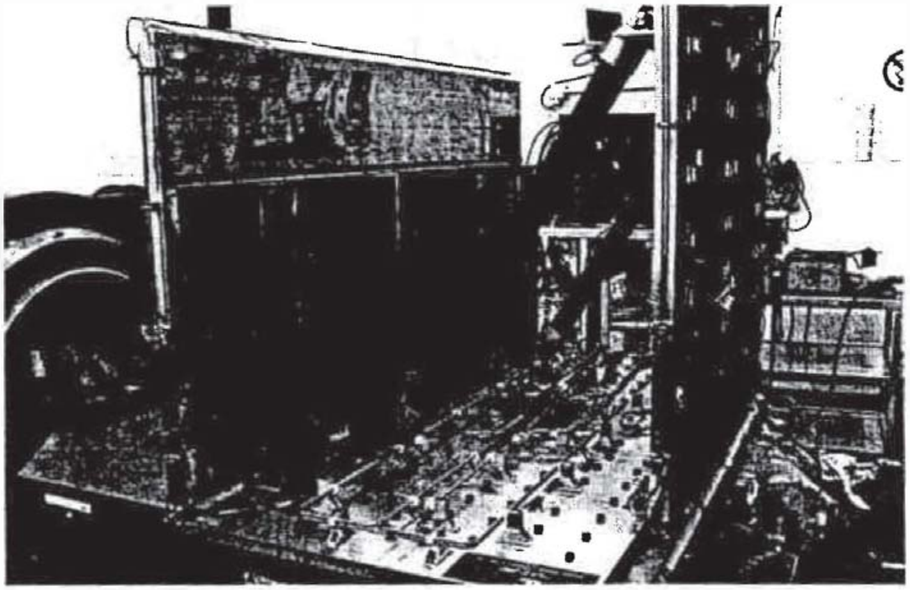

Figure 6 : Laser head thermal control breadboard assembly

The Laser diode Power Supply[1] (LPS) delivers the high current pulse to the laser diodes. The laser power supply has been assessed by breadboard. It is composed of two identical branches, each feeding a series of four diode stacks. One branch consists of a DC/DC charger and a laser diode driver based on a Pulse Forming Network (PFN) technique. The PFN was realized with ceramic capacitors. The output is a pulsed current (85 A nominal, 200 µs duration, 100 Hz rep. rate). The LPS works, as predicted, with a maximum energy about 30% above nominal, allowing to compensate for the diode ageing by increasing the current. The LPS efficiency is also slightly better than predicted (74%). The conducted and radiated emission and the operating temperature range have also been demonstrated as fully compliant with regards to the ATLID requirements. Finally, the current pulse rise and fall time are small enough to induce a negligible efficiency loss in the laser. The LPS design and implementation is now considered as secure after the breadboard results.

5. RECEIVER OPTICS

Key optical elements have been developed, including specific coatings, a narrow-band filter for daylight measurement, and the telescope primary mirror. The following coatings have been manufactured and tested on samples: silver coating for the telescope primary mirror, dielectric non-depolarizing coatings for the receiver optics parts, and high energy coatings (reflective and anti-reflective) for the emitted laser beam before expansion. Performance results were excellent for all samples. A small depolarisation (diattenuation < 0.3%, retardance < 5°) will occur on 45° folding mirrors, but this effect is tolerable. The coating samples have also been submitted successfully to thermal and radiation tests (dose > 2 Mrad). As a conclusion, ATLID coatings are considered as feasible and pre-qualified.

The narrow spectral filter (0.2 nm FWHM) is a Fabry-Perot filter (figure 7). It is composed of an etalon plus a blocking filter in order to select only one etalon order. The etalon spacers are made of Zerodur in order to ensure wavelength stability of the filter. The blocking filter is made of an interference filter coated on a color glass. The peak transmission is higher than expected (0.63 vs 0.50) and the center wavelength is relatively stable versus temperature (0.03 nm per 10°C).

A telescope with a Carbon-Silicon Carbide (C-SiC) primary mirror (0.6 m diameter, F/1) has been selected by ESA for breadboarding. The primary mirror assembly (mirror plus mounts) is being developed. The mirror consists of a C-SiC paraboloid blank on which a SiC layer is vapor-deposited and polished (CVD coating). A detailed design has been defined for the telescope and the blank has been manufactured, weighting 5.7 Kg (figure 8). This mirror will comply with the optical quality requirements (WFE = 1 μm rms), after the polishing operation. SiC-alone technology has also been found compatible with the ATLID requirements.

Figure 7 : Fabry-Perot filter

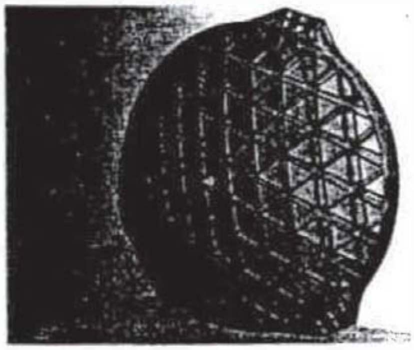

Figure 8 : C-SiC mirror blank

6. DETECTION CHAIN

The chain[4] is composed of a Detector Module and Detection Electronics. The Detector Module includes a Front-End Assembly hybrid on which are mounted a silicon avalanche photodiode (Si-APD), and a transimpedance amplifier (TIA). The APD temperature is controlled by a small thermoelectric cooler mounted on the hybrid. The operating parameters of the APD have been optimised by design and tests. A temperature and a responsivity of respectively 25°C and 12 A/W were selected. The Detector Module also includes a two stage amplifier and a current offset compensation circuit as proximity electronics. The APD is DC-coupled to the amplifier in order to recover the absolute backscatter signal and the background level. The Module is flight representative in terms of optical and thermal interfaces, and volume. The Detection Electronics feature two parallel analog processing chains. The radiometric chain is optimised for high sensitivity, with a low bandwidth (1 MHz). The peak detection chain is optimised for short and strong pulse detection (dense clouds), with a high sampling rate (8 MHz) and a threshold detection. The analog-to-digital convertor of the radiometric chain is a 12 bit ADC, with a sampling frequency of 4 MHz selected for best datation performance. This component is to be qualified next year.

The performance of the radiometric chain has been demonstrated to be very good for the signal-to-noise ratio, down to a few tens of pW signal level. This detection chain also exhibits intrinsic good datation (i.e. ranging) accuracy. The detection chain datation performance has been extensively characterised for all type of clouds and confirmed the choice of two parallel chains. The Detector Module interfaces are compliant with the ATLID requirements.

Parameter	Measured data	Comments
SNR performance		
. useful signal = 60 pW & background = 230 pW	2.0 (spec. 1.2)	best APD operating conditions
. useful signal = 620 pW & no background	15.1 (spec. 9)	
Datation probability performance		
0/+500 ns error range	> 92 %	200 pW cirrus-type profile 0/+ 75 m error (worst case)

Table 2 : Major detection chain performances

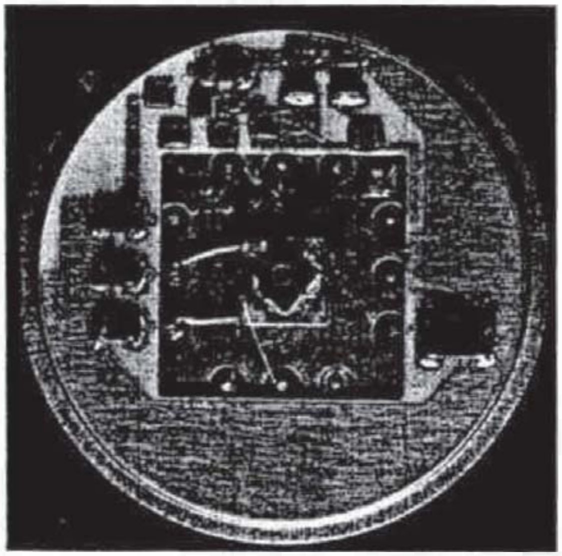

Figure 9 . Front-end hybrid lay-out

7. SCAN MECHANISM

The Scan Mechanism Assembly aims at ensuring the scanning motion of the telescope, while compensating the induced torque by means of a flywheel. The breadboard comprises the Telescope Scan Mechanism (TSM), the Flywheel Assembly (FWA) and a dummy telescope. The dummy telescope is suspended between two (motor and optics-side, respectively) bearings in an isostatic lay-out featuring annular membranes on both end of its shaft. Liquid lubrication of the bearings have been selected in order to meet the lifetime requirement (18 million cycles). The TSM drive box consists of a torque motor (2.6 Nm) and an absolute position encoder (21 bits). The TSM also houses an axial locking device. The scan motion is a sinusoidal profile of +/- 23.5° amplitude and 7-8 sec. period. The torque induced by the telescope motion on the scan axis is compensated by a flywheel in unidirectional motion, which is ac-/decelerated in correspondance with the telescope. A control algorithm, based on a Luenberger observer, generates the telescope and flywheel torque commands from the encoder signals. The algorithm is implemented, for the breadboard, on a digital signal processor (DSP). However, the flight controller could be simpler (phase lead network) with a low bandwidth and sampling frequency (100 Hz). A dedicated motor drive electronics receives the torque commands and supplies the phase currents to the motor windings.

Unit level tests have been performed with regards to the mechanical performance (mass, unbalance, friction torques). In addition, the bearing lifetime has been demonstrated for more than 19 million cycles. System tests have also been performed in order to verify the torque compensation and pointing performances. The torque compensation is achieved to better than 35 mNm (specification 200 mNm). All pointing performances are within specification. The breadboard has been successfully submitted to vibration tests at qualification level and to thermal gradients on the motor.

8. CONCLUSION

ATLID, the European backscatter lidar, is considered a key instrument for atmospheric research. Its is currently included in the payload of the planned Earth Explorer Radiation mission.

The critical technologies for a spaceborne autonomous atmospheric lidar have been developed under the ATLID pre-development program. The following key units have been successfully breadboarded and tested : laser head, pump laser diode power supply, laser thermal control assembly, detection chain, Fabry-Perot filter, scan mechanism and telescope primary mirror.

Thanks to this program, the instrument maturity has been raised considerably in terms of design and technology. Such an instrument is now viable for a near-term development, as requested by the Earth Explorer mission.

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- Alenia (laser)
- Dasa (filter, power supply)
- Zeiss (mirror)
- ORS (mechanism)

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