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Water vapour and wind measurements by a two micron space lidar

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WATER VAPOUR AND WIND MEASUREMENTS BY A TWO MICRON SPACE LIDAR

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ABSTRACT - AEROSPATIALE presents the main results of the feasibility study under ESA contract on a coherent 2 μ m lidar instrument capable of measuring water vapour and wind velocity in the planetary boundary layer. The selected instrument configuration and the associated performance are provided, and the main critical subsystems identified (laser configuration, coherent receiver chain architecture, frequency locking and offsetting architecture). The second phase of this study is dedicated to breadboard the most critical elements of such an instrument in order to technologically consolidate its feasibility.

1. INTRODUCTION

The build-up of future climatological and meteorological global models for weather forecasts and climate predictions will heavily rely on the availability of measurements of wind velocities, atmospheric humidity profile and temperature, with horizontal and vertical resolutions that only space borne instruments can provide.

The first phase of this study is dedicated to define a lidar instrument concept capable to perform the following scientific measurements

- measurement of water vapour content,
- measurement of wind velocity, in the Planetary Boundary Layer (PBL) with a good accuracy and reliability.

This paper presents in §2. the main mission and instrument requirements, in §3. the instrument lidar concept and its associated performance, in §4. the results of the trade-off analyses on the different critical subsystems, in §5. the breadboard designs.

2. MISSION AND INSTRUMENT REQUIREMENTS

The mission and instrument requirements and assumptions are briefly recalled hereafter :

DIAL primary mission	DWL secondary mission
<p><u>Mission assumptions :</u></p> <ul style="list-style-type: none"> • International Space Station orbit, • 2 sampling missions : <p>⇒ "Climatology" : sample a 200 km x 200 km cell several times in 1 month.</p> <p>⇒ Process mission or "enhanced climatology": 600 to 800 km of swath width. Cluster size = 35 km in a cell of 200 km x 200 km.</p> <p><u>Requirements :</u></p> <ul style="list-style-type: none"> • Vertical resolution = 500 m in the PBL, • 10% water vapour accuracy on a single pass in PBL 	<p><u>Requirements :</u></p> <ul style="list-style-type: none"> • Measurement of the Line Of Sight (LOS) component of the wind velocity vector • Minimum nadir angle = 30°. • Wind velocity range : ± 100 m/s • Measurement accuracy : 2 m/s in the PBL (0 to 2 km altitude) • Reliability : > 80 % in the PBL. • Horizontal cell size: 200km x 200km. • Vertical cell size : 500 m • Maximum cluster area : 35km x 35km. • For each cell, a single LOS measurement is accepted

3. INSTRUMENT CONCEPTUAL DESIGN AND PERFORMANCE

3.1 Instrument architecture

The instrument parametric analysis, performed to optimise the instrument concept, has led to the following results :

- a step scanning concept is required for shot accumulation,
- spectral domain selected : 2.06 μ m and 2.09 μ m.
- laser characteristics : > 1 J for both wavelengths, 200 ns pulse duration, 10 Hz pulse repetition frequency.
- transmitter and receiver optics : 0.5 m telescope diameter, 3 μ rd misalignment, 0.7 optical efficiency.
- receiver : 0.6 detection quantum yield, 200 MHz detection bandwidth.

The implementation of the different subsystems was performed to demonstrate the feasibility and assess the typical overall interfaces for an instrument of this class. The baseline carrier for the instrument accommodation is the International Space Station. The instrument is designed to fit a double adapter of the Express pallet, the external attachment interface structure located on the main truss.

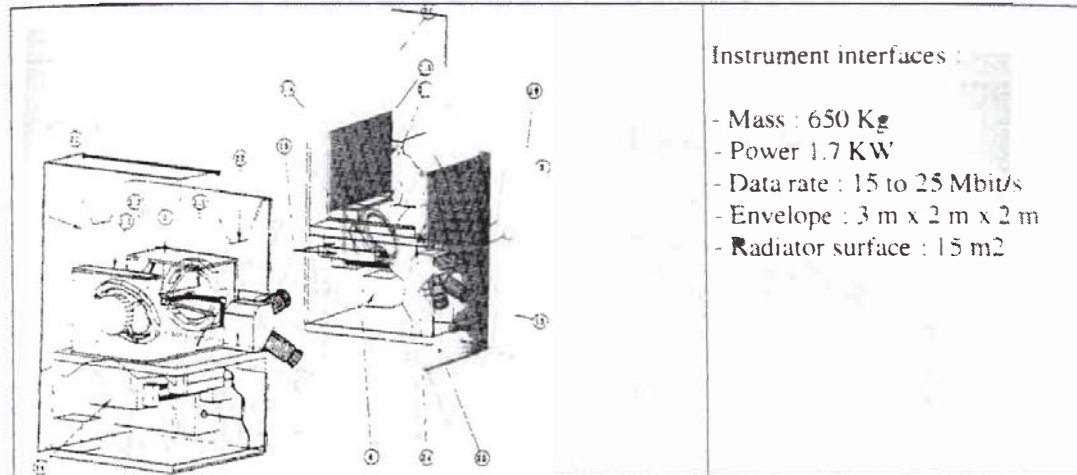


Fig.1 : General layout of the instrument

3.2 Instrument performance

DIAL performance : The accuracy in determining the water vapour content accuracy depends on the actual concentration of the substance. The best performance of 11 % on water vapour accuracy is obtained with a total water vapour content of 20Kg/m². For an increased concentration of 40Kg/m² of total water vapour content, the accuracy decreases to 20%. Moreover, a 3% degradation has to be added to this value to account for systematic errors (wavelength separation between "on" and "off" lines, knowledge of absorption line strength and line width, laser spectral purity, ...).

DWL performance : The DWL performance is summarised hereafter :

- 0.5 m/s wind velocity error in PBL up to 2 km height, with a 99% reliability,
- 5 m/s wind velocity error at 2.5 km height, with a 70% reliability.

For higher altitudes, the major degradation concerns the reliability which rapidly decreases.

To these performance, a systematic error budget evaluated at 0.6 m/s has to be accounted for. These additional errors are mainly due to frequency error difference between the laser transmitter and the local oscillator, frequency drift of the local oscillator, fluctuations of RF oscillator frequency, inaccuracies in the line of sight restitution, and in the knowledge of altitude and velocity of the satellite.

4. SUBSYSTEM TRADE-OFF AND DESIGN

4.1 Transmitter laser subsystem

The objectives of the transmitter laser study were the selection of the best crystal and the optimisation of the laser architecture, in order to achieve high optical energy as well as a good beam quality for the output beam. Simulations of the overall laser performance showed that

Tm:Ho:YAG was the best crystal, which could lead to the optimisation of the system, both in terms of overall efficiency and thermal loads. Concerning the laser transmitter architecture, the only feasible solution, compliant with the energy and pulse repetition frequency requirements, is a laser based on the MOPA scheme presented in figure 2.

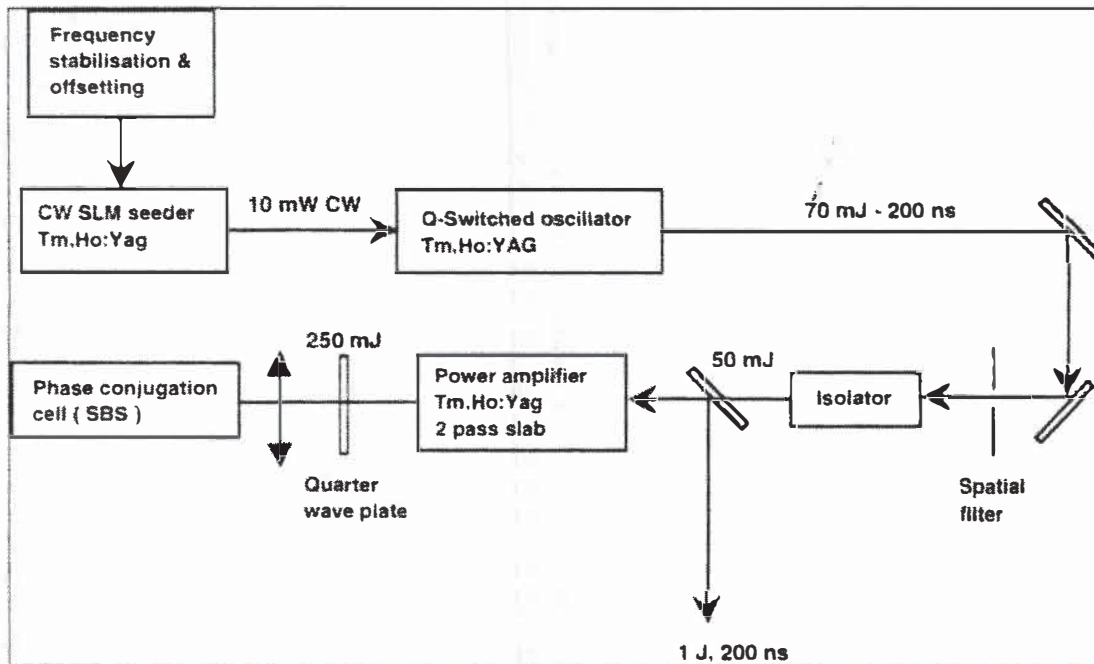


Fig.2 : Transmitter laser architecture (MOPA) for a single wavelength

4.2 Frequency offsetting and stabilisation subsystem

Frequency control requirements are related to both missions of the instrument. The DIAL mission mainly constrains the transmitter laser frequency of the "on" line, due to matching the laser frequency with the atmospheric absorption line. From the receiver point of view, frequency compensation is mainly dedicated to bandwidth reduction.

The requirements for the "off" line, coming from the DIAL mission are less stringent since the transmitted frequency must be centred to the "off" frequency with an accuracy far less stringent than the "on" line.

For DWL mission, wind measurement is performed on the "off" line return. The tolerable residual frequency error after all compensations must be of the order of magnitude of 200 KHz in order to minimise the systematic errors affecting wind velocity measurements.

The two candidates for accurate frequency stabilisation of the lasers were studied :

- the fringe locking technique,
- the Pound Drever technique.

The Pound-Drever option was thus strongly recommended due to better performances. Likewise, two options were studied for absolute frequency reference:

- a calibrated Perot Fabry etalon,
- a gas cell with a reference molecular absorption line.

Several advantages and drawbacks were identified for both options. The final choice between Perot-Fabry etalon and molecular line depends on the availability of the suitable lines and the frequency architecture selected.

An example of the frequency architecture proposed for "on" line is presented in figure 3.

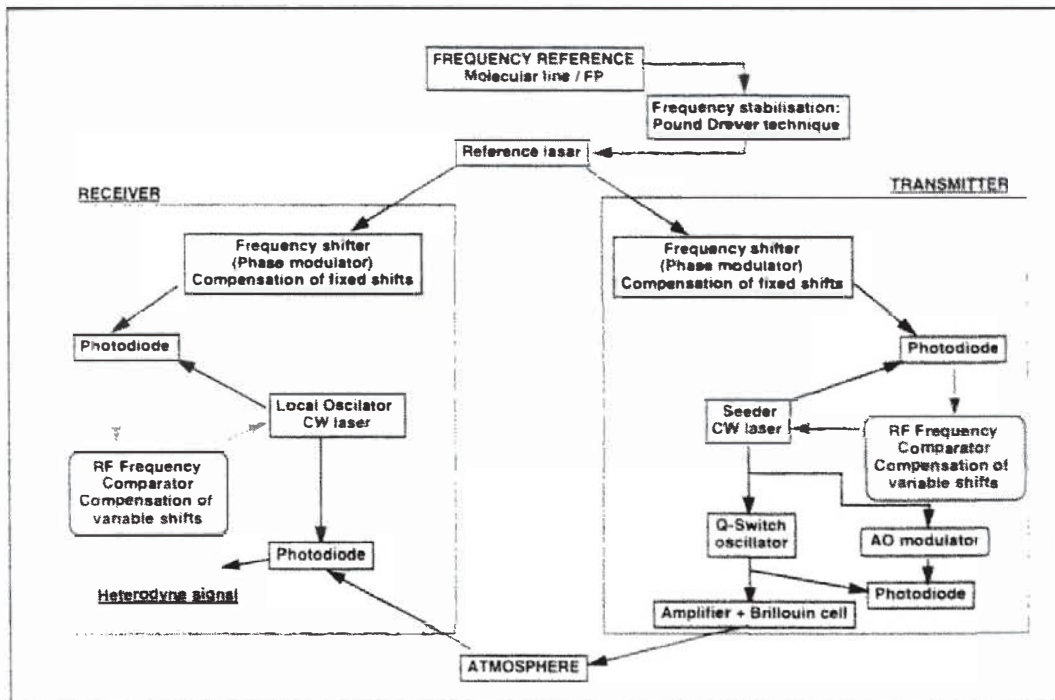


Fig. 3 : Frequency control architecture for "on" line

4.3 Receiver subsystem

An optimisation of the detection chain was required to maximise the output Signal to Noise Ratio (SNR), which is the driver for the achievement of accurate and reliable measurements.

Three receiver configurations have been studied, considering quantisation at different stages of the detection chain : after the pre-amplifier, after the In-phase and Quadrature (I&Q) channels, after the bandwidth reduction filters. The trade-off study has shown that the optimum electronic architecture (figure 4) is the one performing the quantisation after the I&Q demodulation stage. The overall degradation of SNR due to the detection chain is thus typically - 2 dB.

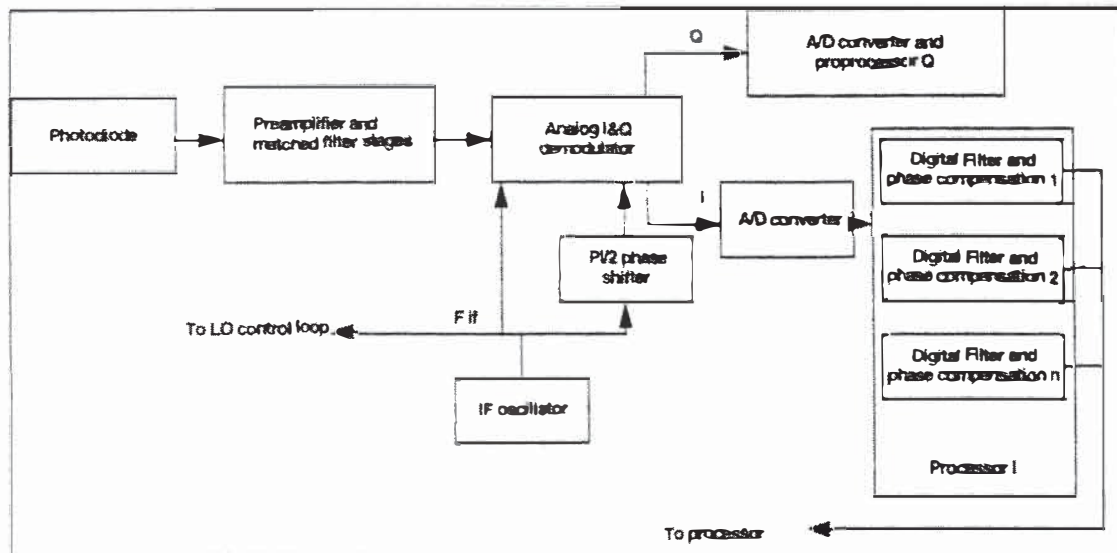


Fig. 4 : Selected receiver architecture

5. BREADBOARD DESIGN

The main goals of the breadboarding activities are the assessment of the technology and the evaluation of the performance limitations for the following critical subsystems:

- a laser delivering a beam with energy per pulse higher than 1 J and closest as possible to diffraction limit.
- a coherent receiver chain with as lowest as possible an electronic noise (< 2 dB).

5.1 Laser breadboard design

The breadboard activities have been focused on the realisation of the oscillator, since the seeder has been already developed and tested in a previous contract (main characteristics of the seeder : 30 mW output energy in single longitudinal mode, < 1.6 diffraction limit, 0.5 MHz linewidth).

The oscillator under development presents an optimised laser head pumping configuration (figure 5), with minimum thermal lensing effects on the beam. The expected performance are around 70 mJ power, 10 Hz pulse repetition frequency and 200 ns pulse duration.

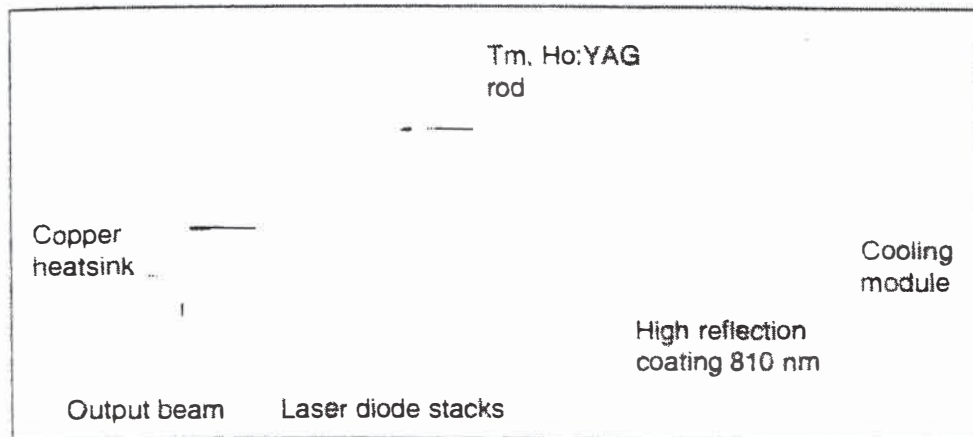


Fig. 5 : Laser head pumping configuration

5.2 Receiver breadboard design

The goal of the receiver breadboarding activity is to characterise the selected architecture of the coherent receiver (see & 4.3). The elements to be tested under representative signal conditions are the photodiode, the transimpedance amplifier, and the matched filter (figure 6).

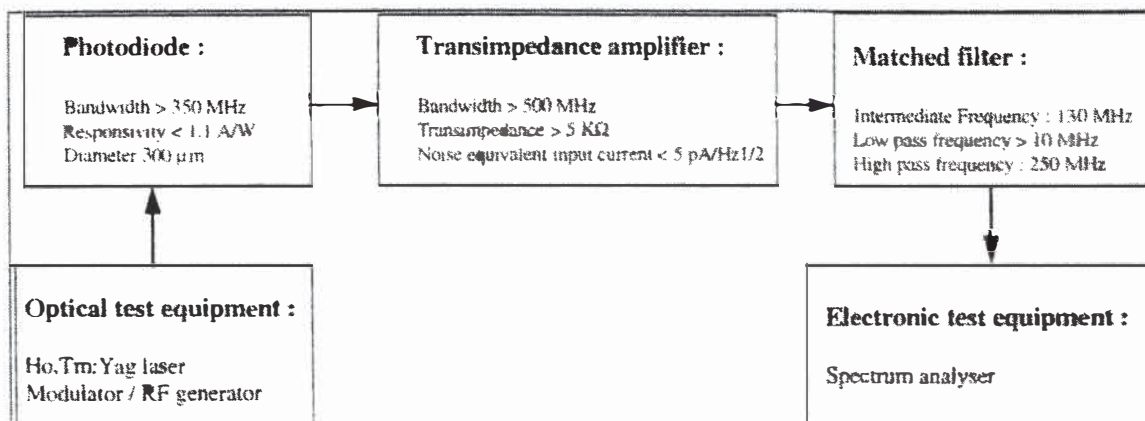


Fig. 6 : Receiver breadboard configuration

6. CONCLUSION AND FUTURE ORIENTATIONS

This study has first demonstrated the feasibility of a 2 μm lidar instrument capable of meeting both missions DIAL and DWL, and provided the mission and instrument performance as well as the main results on the most relevant subsystems.

The designs of the laser transmitter and the receiver breadboards have been presented, and the future works will be their assembly and tests to definitively evaluate the final instrument performance.

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