A SPACEBORNE WIND SOUNDER LIDAR (SBL)

by

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Abstract

This paper presents a commercial oriented *SpaceBorne wind sounder LIDAR (SBL)* system, which is designed for advanced remote sensing purposes. The main objectives of *SBL* are the measurement of wind velocities, by measuring its Doppler shifted reflection from the various atmospheric layers. This represents a unique way to map the three dimensional wind field around the globe.

1 Introduction

The knowledge of our environment is essential for the living in it and for its protection and preservation. The observation of our environment from space provides the ability to monitor and to better understand the Earth/Atmosphere system at the global, regional and local scale. The combination of ranging capability and short wavelength makes optical LIDAR ideally suited for the detection and profiling of clouds and aerosol layers. Wind velocity can be determined from the Doppler shift in wavelength of the back-scattered radiation from these elements. Market studies have shown that this data delivers important information for climate research and weather forecasting agencies and commercial airlines for operation planning and safety aspects.

Despite for the existing need for such measurements a spaceborne wind sounding LIDAR was not realized until now due to the lack of maturity of various essential technologies. Recently, mainly due to advances in military diode pumped solid state lasers, including conductive cooling, rigid and light optomechanical design and the use of an "eye safe" wavelength, the technology enables to design and deploy such a device.

The *SBL* system features for the first time the accommodation of an advanced laser module on a small and dedicated satellite. The laser module will be a eye-safe, diode pumped, conductively cooled solid state laser, which has been developed by ELOP, a member of the SBL industry consortium, and successfully tested for ground operation. The low weight (80 kg) and the low power consumption (app. 200 W) of the payload, as well as the expected life time of 3 years, advantages *SBL* over other current and proposed systems.

The advanced sensor technology combined with a dedicated operational concept will be able to fulfill the application and user requirements concerning the provision, the quality and the continuity of the requested wind profile data.

2 User, Applications and Market

The presented *SBL* system will be a unique contribution to the current remote sensing market in the sense, that it will offer for the first time an operational LIDAR capable to be launched on a small satellite. This will complement to a third category of remote sensing satellite systems next to the well-established optical sensor systems and the new generation of radar satellites, such as the ERS satellites and Radarsat.

A spaceborne LIDAR system mounted on a dedicated satellite will have a number of important uses and applications in Earth/Atmospheric observation which are not addressed by other imaging systems. One of the most interesting application of a spaceborne LIDAR is the measurement of wind profiles by a wind sounding Doppler LIDAR.

Such a Doppler LIDAR transmits a pulse of laser light into the earth's atmosphere and analyzes the backscattered signal to recover the Doppler shift caused by the movement of particles in the various air layers. The advantage of a Doppler LIDAR over similar Radar systems is the shorter wavelength of the laser signal. The LIDAR system is therefore capable to detect much smaller particles, e.g. cloud particles and aerosols, which are moving at the speed of the wind. The altitude and the depth are derived by the time history of the backscattered pulse and the position is controlled by the sensor location. The output of a spaceborne wind sounding LIDAR will be a global 3D wind field, with an extension and accuracy currently not available by existing means. *SBL* will make wind measurements, each representing a 100 km x 100 km x 500 m volume, and with an accuracy of up to 1 m/s (system baseline). The 3D wind field maps of *SBL* will be made available with an updated version on a daily basis (24-36 hours maximum coverage rate dependig on the latitude).

The data of *SBL* can be used for the following specific applications:

- better understanding of the world climate and the prediction of possible climate changes,
- increased skill and accuracy of weather forecasts,
- better operational planning of the global air traffic resulting in time, fuel and cost savings,
- improved safety within the global air traffic.

Based on these applications the *SBL* output would be of great value to users such as:

- climate research and weather forecasting agencies,
- governments/regional authorities and research organizations responsible for monitoring pollution,
- commercial airlines.

All these potential customers can use the data based on an on-line data delivery approach, without additional value adding companies or resellers.

A market estimation for spaceborne wind sounding LIDAR data can not be given in detail at this point due to the lack of comparable market experiences. However, the potential economic benefits can be estimated to be very high based on the fact that such a system will be able to improve the knowledge of the global wind field.

2.1 Spaceborne LIDAR Projects Overview

The largest effort in this direction was taken by NASA, in the LITE mission, where a triple wavelength LIDAR was flown on the space shuttle Discovery as a part of the STS-64 mission in September 1994. Some of the published data shows that a vast amount of useful information can be gathered on LIDAR missions. This short data collection period leads to many proposed and in preparation permanent systems in space, collecting the data all over the globe, like e.g. the ATLID (ATmospheric LIDar) and ALADIN (Atmospheric LAser Doppler INstrument) program in Europe and parallel programs in the USA (such as SPARCLE, a wind sounding LIDAR on the Shuttle) and Japan.

Based on the gathered experiences of especially the LITE mission, future missions are planned, but at the moment **there is no constant monitoring from space** mainly due to the lack of maturity of various essential technologies and due to the problems and the time consuming development needed to manufacture test and deploy a spaceborne laser system for long term operation. The presented *SBL* program takes advantages of recent advances in military diode pumped solid state lasers, including conductive cooling, rigid and light optomechanical design and the use of an eye safe wavelength. This advanced technology enables to design and deploy such a laser module, which advantages *SBL* over other proposed spaceborne LIDAR systems especially in respect to life time, weight, power consumption and cooling methods.

The next Table summarizes the characteristics of other spaceborne LIDAR systems in comparison to the characteristics of *SBL*.

LIDAR System	*LITE*	*ALISSA*	*BALKAN 1*	*PANTHER*	*ALADIN*	*ATLID*	*SBL*
Platform	Shuttle	MIR-1	MIR-1				
Orbit [km]	260	350-400	350-400	200	500	800	**900**
Laser	Nd:YAG	Nd:YAG	Nd:YAG	Nd:YAG	CO_2	Nd:YAG	**Nd:YAG**
Wavelength [nm]	1064/532/ 355	532	532	532	10590	1064	**1064 / 1570**
Pulse Repetition Rate [Hz]	10	50	0.18	0.18	10	100	**up to 20**
Telesc. Diam. [cm]	100	40	27	27	80	60	**50 - 70**
Range Resol. [m]	35	n.a.	3	0.375	250	15	**up to 60**
Scanning	-	-	-	-	±30° conical,step	±23.5°	**±34° conical**
Payload Mass [kg]	990	n.a.	150	150	650	240	**80**
Required Power [W]	2000	n.a.	250	250	1050	450	**200**

Tab. 1: System parameters of spaceborne LIDAR systems

3 Project Description

The main objective of the *SBL* project is the first accommodation of an advanced laser module on a small and dedicated satellite for commercial remote sensing applications. Due to this commercial orientation of the project the system development will feature an innovative approach aimed at following key elements:

- ✓ user dedication,
- ✓ high performance,
- ✓ cost effectivity,
- ✓ fast implementation,
- ✓ short duty cycle.

The major steps of this approach for the development of *SBL* are:

- survey of the market and detailed identification of applications and user requirements as the first development step within the *SBL* project,
- space qualification of advanced, low power and low weight sensor technology already been developed and successfully tested for ground operation,
- fast implementation on a dedicated satellite platform by using
  - proven spacecraft platform concepts
  - existing and space qualified components
  - lean management approaches

  already featured within other projects,
- establishment of a user dedicated operational profile.

This system development approach allows to implement and operate the complete system with a integrated team and tight schedule, which is synonymous with flexibility, fast reaction with regard to user demands and cost effectivity.

Additionally the availability of an affordable launcher via *Cosmos International* (an OHB company) is one of the key elements to enable the low mission total costs.

3.1 System Operation

In order to get a complete and frequent observation of the Earth and its atmosphere, *SBL* will perform a specific conical scan method displayed in Figure 1 on the enxt page.

In this scanning method the laser pointing axis forms a continuos spiral, covering the Earth within the boundaries of a sensor swath comparable to that of a scanning pushbroom sensor. The observation spots of the sensor will be lined up on this spiral with more or less distances between each other according to the pulse frequency of the laser on the one hand and the shape of the scan pattern on the other.

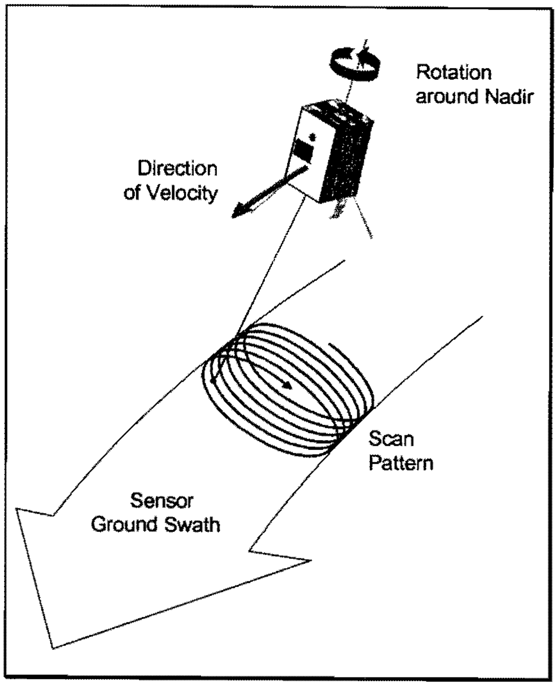

Fig. 1: Scan performance of *SBL*

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The width of the *SBL* sensor swath is a function of the chosen off nadir viewing angle, i.e. the cone angle of the platform's rotation. The off nadir angle of *SBL* will be ±34° as a baseline, resulting in a sensor swath width of about 1260 km at the equator. The position of the subsequent sensor swaths to each other, being a function of the satellite orbit, will be chosen in order to prevent gaps between the swaths and to minimize the period which is necessary for the complete coverage of the Earth. The baseline of the *SBL* target orbit will be near polar (inclination ~ 86°) with 900 km altitude. This orbit reveals an optimal long term coverage performance of the sensor, with a complete coverage of the Earth within 24-36 hours, depending on the latitude

The rotation of the satellite platform around the nadir axis is necessary to form the "circles" of the scan pattern. The period of this rotation will be chosen to get a specific shape of this pattern. At a given orbit and therefore orbital velocity of the satellite, a long rotation period will form a stretched spiral with long distances between each "circle" and a short period will result in a spiral with shorter distances between the "circles". The combination of the rotation period of the platform and the pulse frequency of the sensor will effect the position of the observation spots on the earth and in the atmosphere layers, respectively. The observation spots will form a grid which corresponds to the shape of the scan pattern. Because of the fact that *SBL* needs two observation points for the determination of the wind velocity, these two observation spots will be located inside the 100 km x 100 km square, which is the envisaged baseline horizontal resolution of the system.

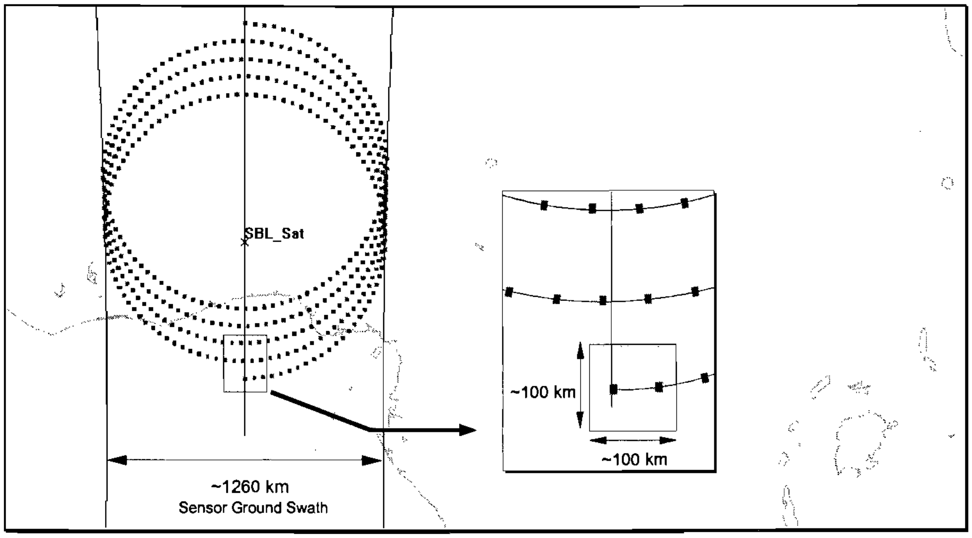

Fig. 2: Observation grid of the *SBL* sensor

The observation grid of *SBL* is shown in Figure 2. The corresponding rotation period of the platform is 15.4 s and the pulse frequency 5,1 Hz. Within the operation of the satellite, the resulting resolution can be varied during operation due to user demands. This can be done by changing the rotation period and the laser pulse frequency, respectively. The laser itself operates at a baseline pulse frequency of 20 Hz, thus enabling extra system margin.

3.2 *SBL* Sensor

The *SBL* sensor consists of the following *central elements*:

- diode pumped conductively cooled solid state laser,
- light weight telescope,
- high sensitivity detector.

The laser has been developed for ground based applications and will adapted for space operation. The expected life time of this laser is longer than the duration of flash pumped lasers, which are presently the only ones available. It can operate at a pulse repetition rate of up to 20 pulses per second.

The light weight telescope objective has a aperture of about 500 mm. This mirror type telescope is similar a telescope developed for a space astronomical observatory. The latter was designed to meet the strict requirements of space operation and has been fully tested and qualified for these specifications.

The high sensitivity receiver records the returned echoes and will be based on existing technology.

Additional *supporting elements* of the sensor will be as a baseline:

- power supply unit for all elements,
- payload control computer,
- data processing unit.

It has to be pointed out that no extra transmitter and antenna are necessary for the transmission of the *SBL* wind sounding data. The data transmission can be done with a low-cost S-band transmitter and antenna used for the TM/TC purposes.

The block diagram of the baseline *SBL* sensor elements and their configuration is displayed in the following Figure 3.

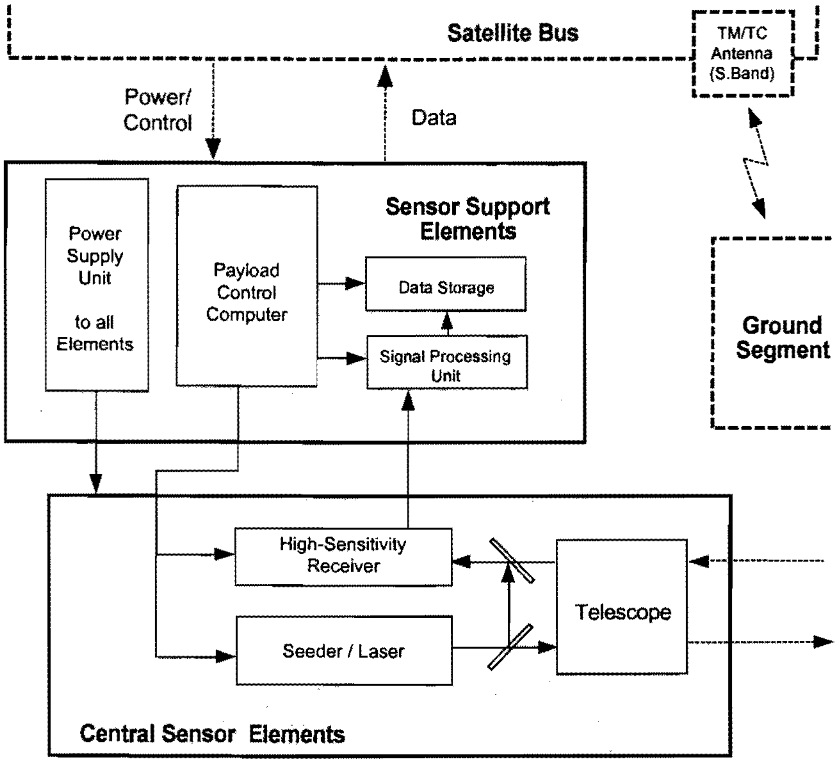

Fig. 3: *SBL* Sensor Block Diagram

The main advantages of this *SBL* sensor are as follows:

- The diode pumped solid state, laser module, already developed and approved for military uses, allows long laser life time in space.
- The current design can provide, if needed, an eye safe wavelength, and by doing so minimizing the risk of eye damage.
- The low weight and high efficiency allow the use of a small satellite platform configuration.
- The conductivity cooled laser design is of major importance, as the use of cooling liquids is costly and complicated for small space platforms.
- In the presented program the scanning motion is performed by the platform and no extra scanner is used.

The following *SBL* sensor parameters can be summarized:

- *Telescope*
  - Type: Ritchey-Chretien (mirrors)
- *Transmitter*
  - Type of Laser: Diode pumped solid state, Nd:YAG
  - Wavelength: 1.064 or 1.570 µm (eye-safe)
  - Average Power: 4 - 8 W
  - Pulse Energy: 200 - 400 mJ
  - Pulse Duration: app. 100 nsec
  - Repetition rate: up to 20 Hz
- *Overall System*
  - Weight (central elements): 80 kg
  - Power Requirement: app. 200 W
  - Dimensions (Telescope - Receiver): app. 50 cm
  - Data Rate: app. 50 Mbit/orbit (S-band is sufficient for downlink)
  - Height Resolution: up to 60 m
  - Expected Horizontal Resolution: ≤ 100 km
  - Expected Accuracy: up to 1 m/s
  - Lifetime in Space: > 3 years

3.3 - Spacecraft Bus

The *SBL* satellite bus will be developed in responsibility of OHB-System. This will be done in respect to the objectives and the specific operational profile of the *SBL* mission and the efficient development approach described earlier.

Since the dynamic of the system shall be obtained during the complete nominal operation of the system, is a crucial requirement for the development of the satellite bus. The major aspects are:

- to produce and obtain the specific motion of the platform, which is required to operate the sensor with the optimum performance,
- to ensure the proper functionality of the complete system even within these special dynamic conditions,
- to generate the power required.

The investigation of the spacecraft bus and its subsystems are particularly taking into account the following elements:

- *ACS subsystem,* as responsible and necessary for the variable attitude dynamic of the spacecraft platform and therefore for the pointing of the sensor.
- *Power conditioning,* as responsible for the conditioning of the 250W peak power required by the sensor at any illumination condition at the given spacecraft dynamic.
- *TM/TC subsystem,* responsible to ensure the TM/TC and real-time data transmission contacts at the given dynamic of the spacecraft.
- *Mechanical, electrical and thermal aspects* for payload integration.

3.4 - Ground Segment

The Ground Segment of the *SBL* project will be designed to fulfill the scientific and commercial user requirements concerning the provision, the quality and the continuity of the requested observation data. Due to the fact that a specific data receiving station will not be necessary, the *SBL* ground segment can be subdivided into:

- Control & Data Receiving Station

  This includes one ground station for the complete control of the space segment in respect to the operational concept and for the reception of the *SBL* wind sounding data. Additionally this ground station will house all capabilities necessary for the processing of the data and its transmission to the final user. For the Control & Data Receiving Station a location in the polar region is planned.

- Data Evaluation and Assessment

  A data evaluation and assessment will be done within the satellite operation phase by the final users. User demands can be stated in order to state specific wishes concerning the satellite data and to optimize the overall operational concept.

The outcome of the *SBL* system will be generated 3D wind field maps on a daily basis. The data transmission to the final users will be done by means of conventional data transfer links like, like internet. Direct and high speed communication links will be investigated to be used in those cases in which the speed of data delivery to the user is essentially affecting the quality of the data. This the time critical aspect can be relevant for the knowledge of the actual wind field as necessary for e.g. the operation planning of the air traffic.

4 Project Schedule

The *SBL* project is scheduled to start in the second half of 1998 with the Concept Definition and System Feasibility Phase A. The launch of *SBL* is scheduled for mid 2002, followed by three months commissioning and a three year operational phase. The complete schedule of the *SBL* Project is given in the following Figure 4.

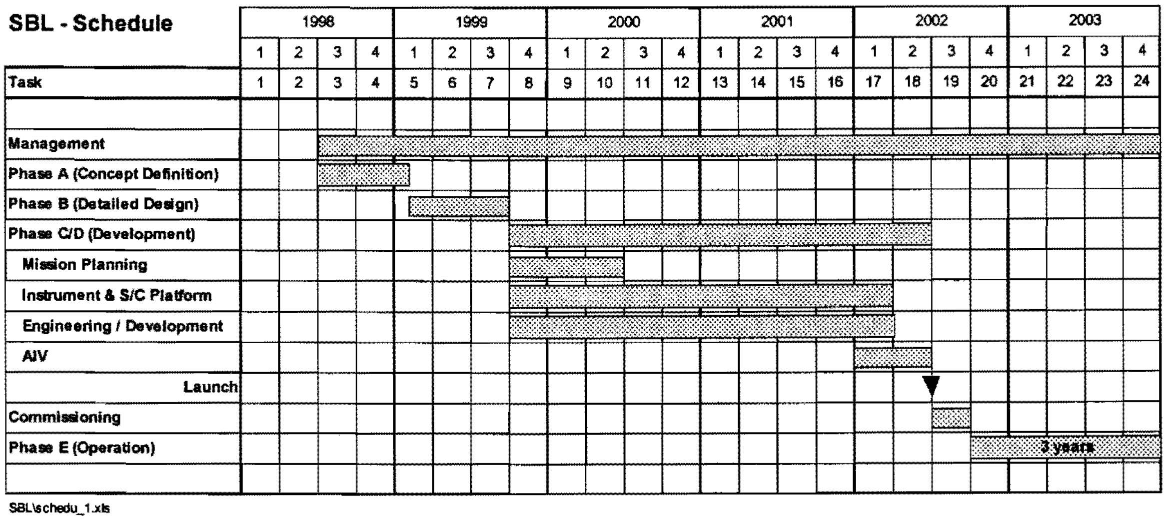

Fig. 4: Schedule of the *SBL* Project

5 Conclusions

The presented *SBL* system will have important benefits concerning technical and economical aspects. Important technical benefits can be identified as the following:

- demonstration of the feasibility to develop and operate the first low weight and low power spaceborne LIDAR,
- gaining a high level of technical knowledge for usage of spaceborne LIDAR data and for the extension of the worldwide remote sensing market,

Other main benefits are expected on the economic and humanitarian sector. As explained *SBL* will have a number of important uses in Earth/Atmospheric observation which are not addressed by passive imaging systems. The main impacts of the data collected from the *SBL* will be as follows:

- *SBL* will offer a new kind of valuable data sources for the understanding of the world climate and the prediction of possible climate changes.
- The data will provide better weather prediction ability, water resources management as well as a good basis for global wind monitoring, an important parameter for flight safety, weather prediction, and disaster damage reduction.
- *SBL* can offer valuable data for commercial applications, e.g. the saving of valuable time and fuel resources within the increasing international air traffic.
- *SBL* will be able to provide base data for future pollution monitoring DIAL laser satellites will enable a faster world ozone depletion and global pollution monitoring.
- The *SBL* data provided will enhance theoretical work, academic work and model verification work to be carried out at European universities.

Due to the presented special capabilities and the expected benefits the *SBL* system has a high commercial potential.