The BELA - The first European Planetary Laser Altimeter: Conceptional Design and Technical Status

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Abstract

The BepiColombo Laser Altimeter (BELA) is the first European laser altimeter for planetary exploration which has been selected by ESA for flight aboard ESA's Bepi Colombo mission to planet Mercury. A consortium led by the Physikalisches Institut Bern and Institut für Planetenforschung (DLR-Berlin, Germany) will develop a laser altimeter based on the classical principle of laser pulse time of flight measurement. The instrument is based on a longitudinally pumped Nd:YAG laser with 50mJ pulse energy and pulses of about 3ns duration, operating nominally at 10Hz repetition rate. The BELA requirements, the conceptional design, the technical development activities and their status are presented during the workshop.

Introduction

BepiColombo is the European Space Agencies (ESA) cornerstone mission to the planet Mercury. It consists of two orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). Among the instruments that have been confirmed is the Bepi Colombo Laser Altimeter (BELA). BELA's primary goal is:

- develop a full topographic map of the planet with an accuracy (goal) of 1m to support geomorphologic studies,
- explore Mercury's interior structure by joint analysis of topographic, gravity and rotation data,
- determine elastic properties of the planet by measurements of tidal deformation
- measure surface albedo and roughness,
- support spacecraft navigation.

Main Requirements

The instruments key requirements are:

- Global topographic mapping with height accuracy of 10m wrt. COM (goal: 1m),
- Surface spacing 300m (shot to shot),
- High detection probability (>70%) up to 1000km,
- Laser footprint <100m.

The detection probability is defined by the PFD, the probability that a random noise fluctuation in the pulse detection chain is misinterpreted as a laser echo.

These requirements have to be fulfilled under the harsh environmental conditions at Mercury. The main design drivers for the instrument are:

- high thermal- and solar flux,

- to guarantee an alignment stability of a few arc seconds
- cosmic radiation levels,
- low resources (e.g. mass)

The main demands come from the high thermal flux (that is as high as 10kW/m^2) and the high Temperature of Mercury, which can reach surface temperatures of up to 700K. The total instrument mass must not exceed 12kg, which limits the size of the receiver and the laser transmitter.

Technical Approach and Design

The BELA instrument consists of the receiver and the transmitter part which will be developed by institutions from Switzerland, Germany and Spain. The architecture of the instrument is shown in Figure 1.

The receiver telescope with the detector, the laser head and the beam expanding telescope are assembled on the so called Baseplate (BP) unit. The laser head, (OAB), is fibre pumped by the pumped-diode unit (PDU) which is controlled by the laser electronics (LEU). The main electronics of BELA including rangefinder electronics, data processing electronics, transmitter electronics (START-pulse detection and digitization) and the power supply are accommodated in a common electronics box,(ELU).

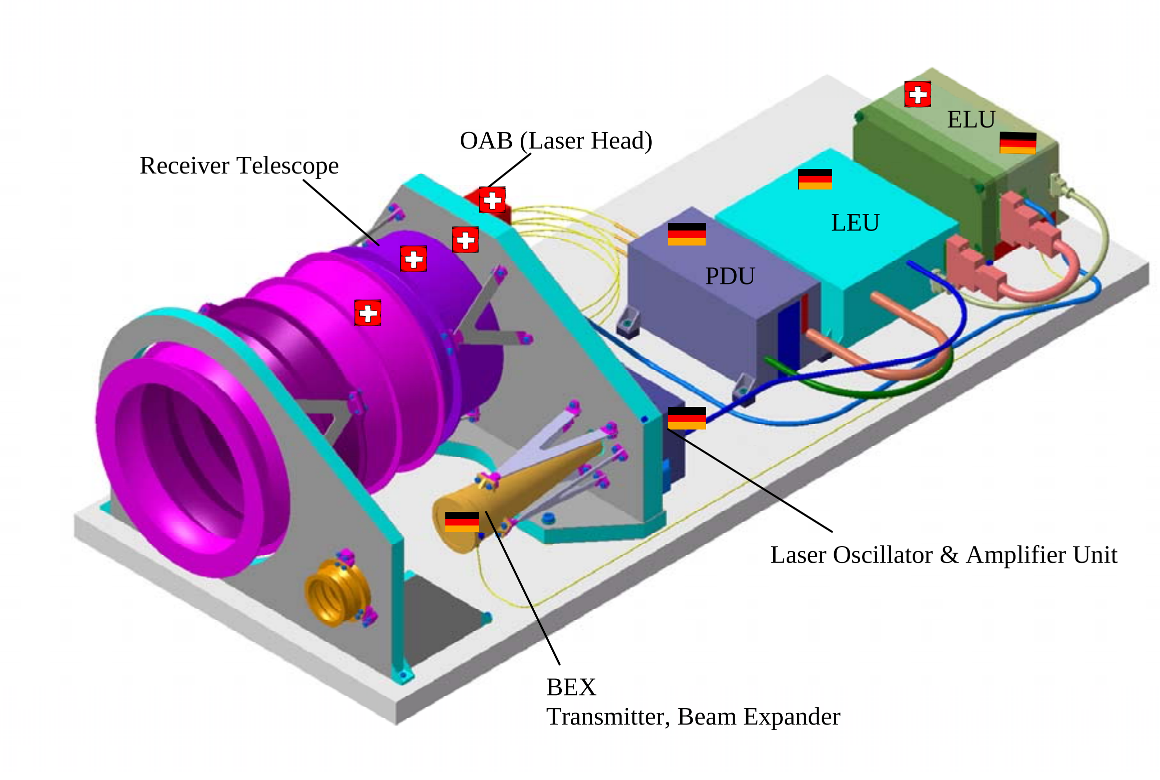

Figure 1: *Main Components of the BELA Laser Altimeter*

The main characteristics of the envisaged instrument are:

- 20-25cm lightweight telescope (1kg) with large baffle for thermal protection,
- backend optics with 1nm filter /FWHM) and >80% transmission,
- high sensitive (low noise) APD detector,
- 50mJ, 3ns diode pumped Nd:YAG laser, 10Hz nominal repetition rate,
- 50mm (20x) beam expander with ~50m footprint @1000km,

- common E box (ELU) with receiver-, START electronics and LEON-3 processor, power converter, thermal controller,
- 12kg, 33W (nominal).

The instrument's characteristics were derived by performance simulations according to the following parameter spreadsheet (see Table 1).

Table 1: *BELA parameter set for performance simulation*

Parameter	Symbol	BELA
S/C		
Destination		Mercury
Altitude	H	400-1500 km
Pointing uncertainty	$\delta\varphi$	25µrad
Laser transmitter		
Pulse energy	E_r	50 mJ[a]
Pulse width	δ_0	3.4 ns[b]
Wavelength	λ_T	1064 nm
$1/e^2$ beam divergence	θ_T	25 µrad[c]
Repetition rate	v_T	10 Hz
Collimator efficiency	ϵ_T	0.80
Receiver optics		
Arperture radius	r_R	125 mm
Focal length	f_R	1250 mm
Field of view	θ_{FOV}	200 µrad[c]
Optical efficiency	ϵ_{RO}	0.70[d]
Filter transmission	ϵ_{RF}	0.80
Filter bandpass	δ_{RF}	0.42 nm[b]
Detector		
Quantum efficiency	ϵ_{QE}	0.38
Gain	M	150
Excess noise index	χ	0.25
Surface dark current	I_{DS}	20 nA[a]
Bulk dark current	I_{DB}	50 pA[a]
Electronics		
TIA Bandwidth	B_0	20 MHz
ADC sample period	T_R	12.5 ns
Noise floor	δI_{NF}	1.0 pA $Hz^{-1/2}$

The most critical parameters are the laser pulse energy, the aperture of the receiver telescope and the performance characteristics of the detector (quantum efficiency, noise). It was estimated that the instrument will be capable of meeting the performance requirements, PFD<0.1 out to a height of 1050km and a height accuracy measurement of down to 1m for a reasonable set of observing conditions.

Key instrument components are presently in development for performance verifications and testing. One key component, the laser units has already been designed and fabricated by MPS and German industry (Laser Zentrum Hannover e.V., DILAS GmbH, Mainz, Von Hoerner & Sulger, Schwetzingen) as a prototype model, which is shortly described below.

The BELA-Laser

The optical design of the BELA laser is based on the concept of Nd:YAG laser crystals for the oscillator and the two amplifier stages, which are longitudinally pumped with GaAs diodes around 804 to 808 nm (@298K). The simplified block diagram of the laser head (OAB) and the pump diode unit (PDU) is shown in Figure 2.

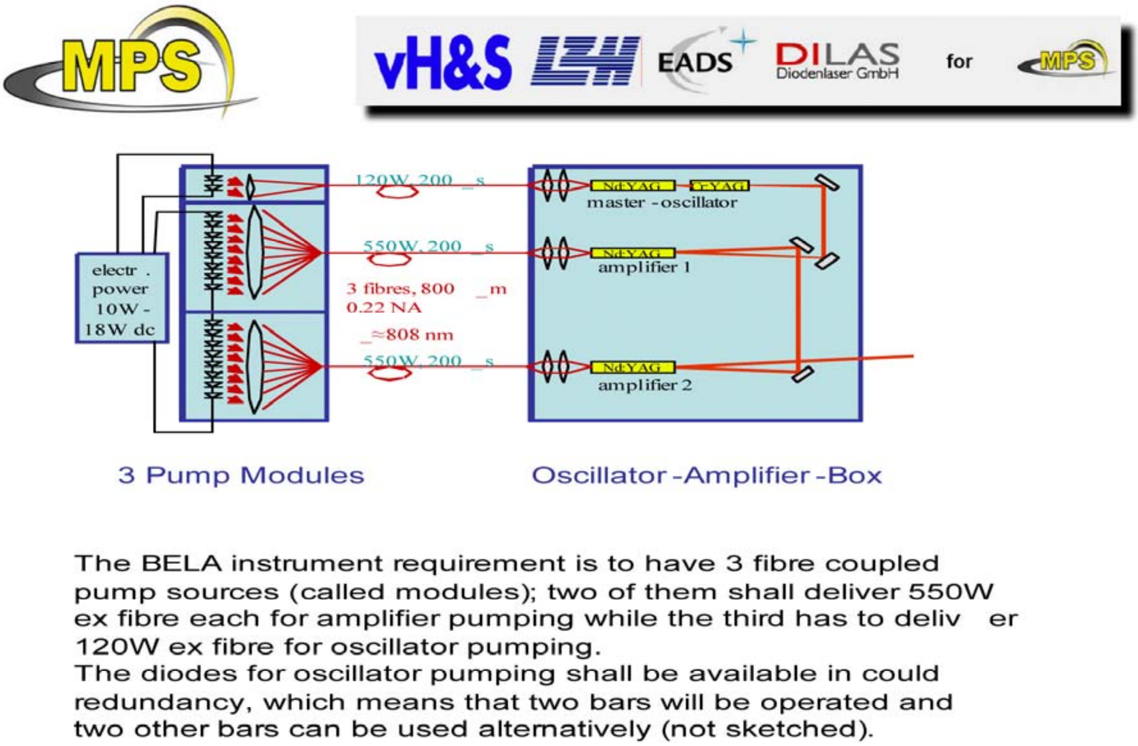

Figure 2: *Block diagram of the laser head (OAB) and the pump diode unit (PDU)*

The OAB is optically pumped via three fibre optics cables between the OAB and the PDU. The output pulse energy of the laser is 50mJ at 3ns pulse duration (measured) and a firing of 10Hz (nominally). The control and the current supply of the laser are provided by the Laser Electronics Unit (LEU). The main parameters of the laser are summarized in Table 2.

Table 2: *Laser Main Characteristics*

Parameter	**Unit**	**Value/Description**
Material		Nd:YAG
Wavelength	nm	1064.x
Pulse Energy	mJ	50 (EOL)
Pulse frequency	Hz	10 (nominal)
Pulse Duration	Ns	3
M2		<1.6 (measured: 1.3)
Q-switch		Passive
Laser Pump		Longitudinal
Efficiency (electro-optical)	%	5.2 (measured)

The first Prototype Model of the laser is shown in Figure 3.

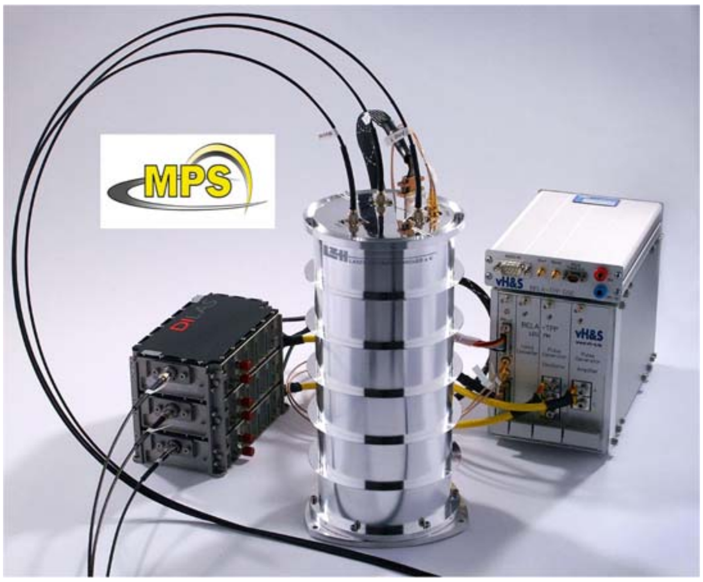

Figure 3: *BELA Laser Prototype Model-1*

Further key components that are presently in development are only shortly listed below:

Beam Expander (BEX)

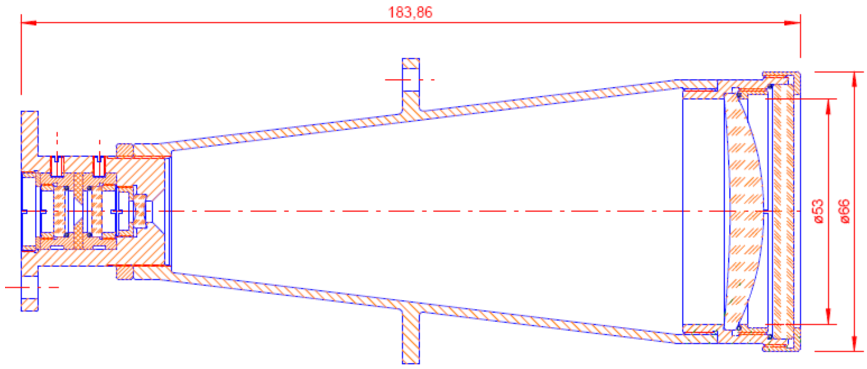

Figure 4: *Opto-mechanical layout of the BELA Beam Expander (BEX)*

The BELA beam expander (Prototype Model) is based on an aspheric lens design for the exit-lens in order to prevent a double-lens and to save mass. The beam direction can be slightly adjusted by wedge prisms at the entrance of the beam expander. The BELA-BEX has a nominal beam expansion ratio of 20. A fibre-optics interface is foreseen for optical detection of the START-pulse.

START Electronics

The START electronics has two functions:

1. detection of the START-pulse, which will be fed to the rangefinder electronics
2. digitization of the START-pulse for energy and shape measurement of the outgoing pulse

The block diagram of the START electronics and the first prototype is shown in Figure 5 and Figure 6 respectively.

The components of the receiver: telescope (incl. base plate), baffle, detector and rangefinder electronics are presently in development in Switzerland, lead by the University of Bern (Nicolas Thomas and Karsten Seiferlin).

Conclusion and Outlook

The BELA team is in process to design the first European laser altimter for planetary exploration which has been selected by ESA for flight aboard of ESA's Bepi Colombo mission to planet Mercury. Numerical models have been developed to assist with design tradeoffs and definition of operational modes. Key components like the laser have been developed as prototype model and further units are in fabrication (beam expander, receiver telescope, detector electronics).

The Forschungseinrichtung Satellitengeodäsie der Technischen Universität München (Wettzell) and DLR are presently in process to design a first performance demonstrator which is based on the BELA prototype models and commercial components with a performance characteristics close to BELA. This performance demonstrator will be used for functional and performance verification of BELA by satellite laser ranging, and it will be used as a transponder demonstrator.

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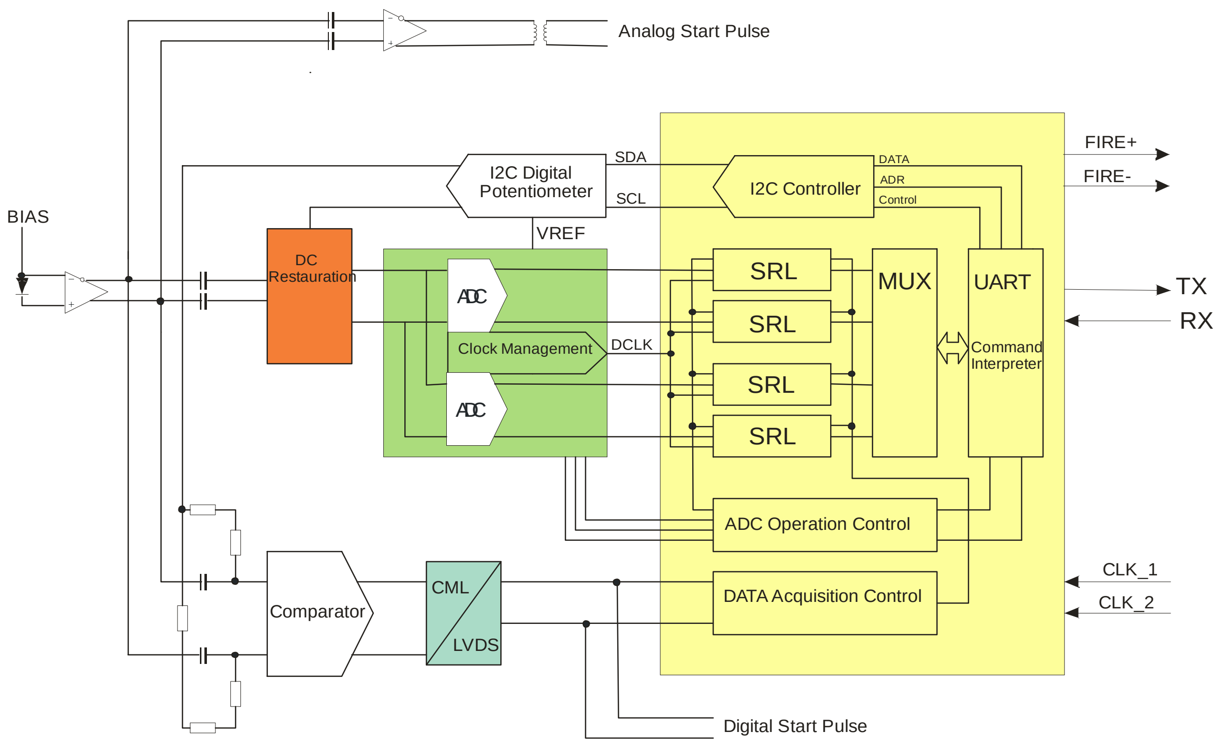

Figure 5: *Block Diagram of the START-Electronics*

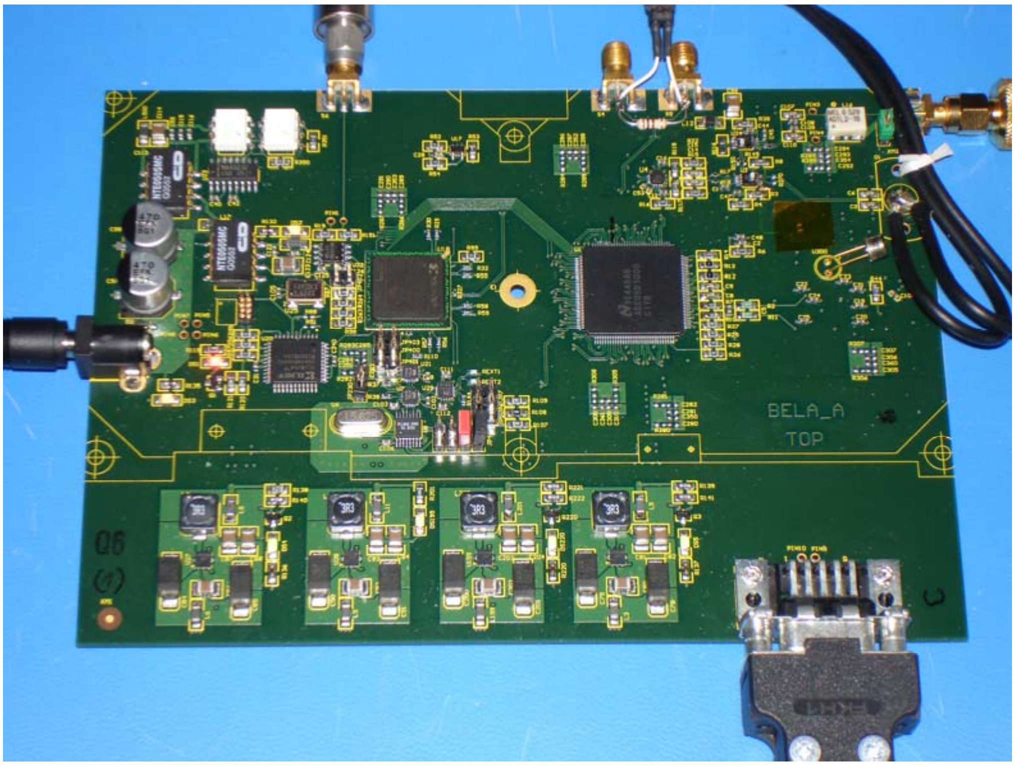

Figure 6: *Prototype of the START Electronics*