International Conference on Space Optics—ICSO 2022

Dubrovnik, Croatia

3–7 October 2022

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

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International Conference on Space Optics — ICSO 2022, edited by Kyriaki Minoglou, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 12777, 127773A · © 2023 ESA and CNES · 0277-786X · doi: 10.1117/12.2690347

European laser delevopment for LISA

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ABSTRACT

We present the European development of an engineering model Laser Head for LISA. This single box includes a seed laser, an electro-optical phase modulator, a fiber amplifier and all PCBs to operate the Laser Head.

Keywords: LISA, laser, fiber amplifier, space, gravitational waves, engineering model

1. INTRODUCTION

The goal of the future space-based gravitational-wave detector Laser Interferometer Space Antenna (LISA) is to detect gravitational waves by laser interferometry. On-board each LISA S/C are two operating (plus two cold redundant) Laser Heads (LH) whose beams are exchanged between the S/C to measure distance changes between the free-falling test masses inside the S/C. This requires a laser of excellent frequency stability, a low relative intensity noise, and a continuous optical output power higher than 2 W emitted at 1064 nm.

In December 2021, LISA completed its Mission Formulation Review, now entering Phase B1. The European Space Agency (ESA) is pushing the development of all critical technologies towards TRL 6 until the end of Phase B1. One of those technologies is the laser. In parallel to the European laser development, the NASA is working on a Laser Head for LISA [1, 2, 3].

The scope of the European laser development changed from an extended cavity diode laser (ECDL) with resonant optical feedback as a seed laser [4, 5] to a non-planar ring oscillator (NPRO) laser that is similar to the one used for LISA Pathfinder [6]. Despite the change of seed laser technology we could use our knowledge on fiber components and requirements on the electronics gained in the breadboard phase for the development of the engineering model (EM) presented in this article.

2. LASER HEAD

Figure 1 depicts a CAD of the EM Laser Head. It comprises the seed laser (a TESAT RLU), a phase modulator, components of the fiber amplifier, an optical output switch, and the electronics to drive and stabilize the laser. It consists of five compartments that are stacked. The baseplate provides the mechanical and thermal interfaces to the S/C and has a footprint of 302 mm times 302 mm. The height of the LH is 196 mm and its calculated mass is 14.3 kg.

Threaded interconnections between the five compartments provide the necessary stiffness of the overall system. The first eigenfrequency is at 524 Hz (see Figure 2) which is well above the requirement of 100 Hz.

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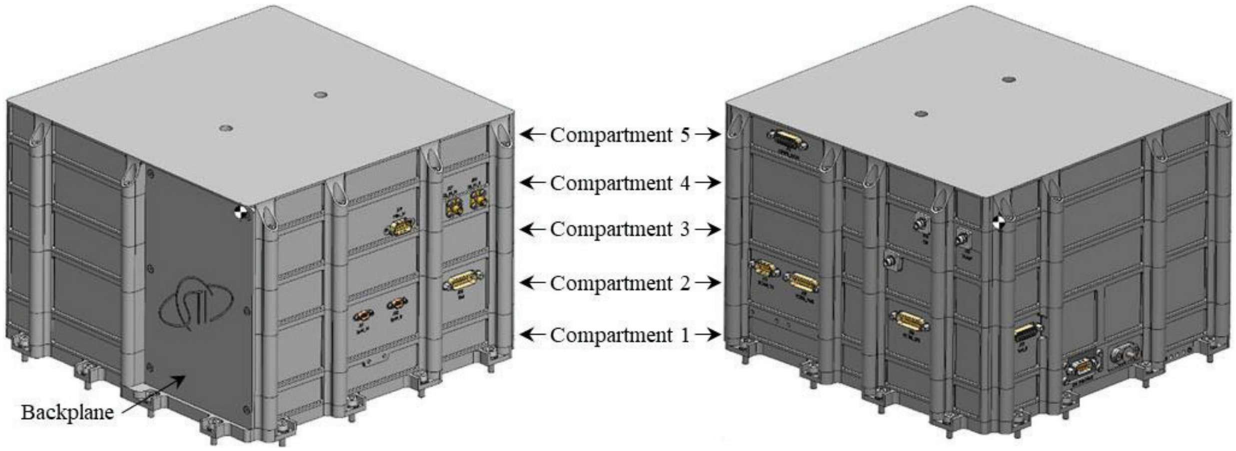

Figure 1. CAD of the EM Laser Head.

The electrical connection between all frames is managed via a backplane PCB. This backplane is covered with a separate lid. Compartments 2 and 5 contain all necessary interfaces for the electrical connectors. Compartments 3 and 4 contain most of the optical equipment parts for the fiber amplifier and dedicated electronics.

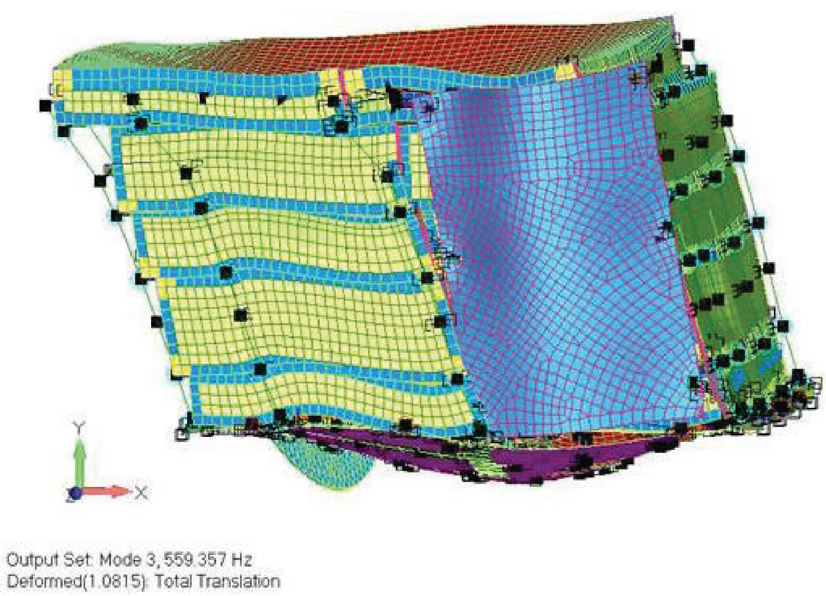

Figure 2. First main mode in x at 559 Hz (in-plane).

The LH has three optical Mini AVIM connectors as output: one connector for delivering a fraction of the light to the Laser Pre-Stabilization System (LPS) – an optical reference cavity to stabilize the laser frequency of the LH by means of a Pound-Drever-Hall lock. The other two connectors are for switching the optical output power of 2 W between the LISA Optical Bench (OB) and a beam dump. This switching functionality maybe requested for constellation acquisition sequence of LISA.

The LH design features redundant electrical interfaces (except for power supply), components, and electronic assemblies. The electronics implements the following functionalities:

- interface to the seed laser,
- pump laser drivers,

- EOM driver for 2.4 GHz modulation and pseudo-random noise code modulation,
- interface to the LPS and the phasemeter,
- temperature acquisition and control,
- connection of command and control lines of the fiber optical switch,
- monitor and control of optical power including the connection to the external photodetectors for relative intensity noise stabilization located on the Optical Bench,
- secondary power supply, and
- synchronization to a common clock.

Parts of the control loops are implemented in analogue others in digital electronics. The central device for the digital control is a micro-controller. For the EM LH, the implementation of the LH operation is split into a microprocessor part and a LabVIEW part. The LabVIEW implementation interfaces with the microprocessor via an UART interface; a SpaceWire interface is also available, but not used for the baseline of the EM. Thereby, the LabVIEW emulates the S/C interface that provides the tele commands to control the LH and provides an easily accessible user interface. Figure 3 depicts an overview of the setup used to operate the EM LH.

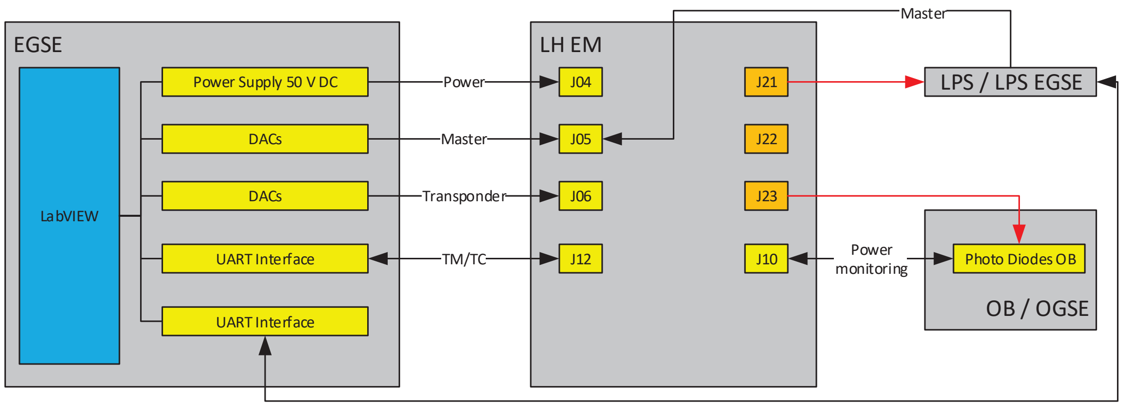

Figure 3. Overview of the setup to operate the EM LH.

For the EM LH the micro-controller is in charge of the real time functions, fast control loops, and the hardware interface whereas the electronic ground support equipment (EGSE) is taking care of slow control loops, the user interface to the LH, and the mode control. Table 1 lists the operational mode of the EM LH and Figure *4* shows the corresponding user interface to command the LH to switch between these different modes.

The LabVIEW system includes a mode logic that translates operational modes to combinations of TMTC parameter values and sends out tele commands to the LH in order to realize the physical state of the LH that corresponds to the intended operational mode. The microcontroller itself includes a state logic that ensures that no harmful hardware settings can be chosen.

Table 1. Brief description of the different operational modes of the LH implemented for the EM.

Mode	**Mode Description**	**Transition possible to Mode**
0 (Off)	Power supply is off.	1
1 (Stand-by)	The LH is ready for commands from the ICC/OBC to set operational parameters or transition to other modes.	0, 2
2 (Dark warm)	Laser operation is on, but light is dumped via the optical switch, i.e., no light is emitted towards the OB.	0, 1, 3
3 (On)	The LH emits light towards the OB according to the set power level, but RIN and frequency noise requirements are not met.	0, 1, 2, 4
4 (Free-running)	The LH emits light towards the OB, the optical power level is locked by the RIN control and the (free running) frequency noise requirement is met.	0, 1, 3, 6, 7, 8

Mode	Mode Description	Transition possible to Mode
6 (Master)	The LH emits the nominal optical power towards the OB; the optical power level is locked by the RIN control. Three sub modes are implemented for the frequency noise control:	
	• Sub mode A (SCAN): The LH frequency is scanned over at least two resonances of the LPS.	0, 1, 4
	• Sub mode B (ACQUISITION): The LH performs an automated frequency scan and automatically locks to the closes transmission peak of the LPS cavity.	0, 1, 4, 6C
	• Sub mode C (LOCKED): Entered autonomously from ACQUISITION mode when successfully locked onto a transmission peak. The RIN and frequency noise requirements are met.	0, 1, 4
7 (Transponder)	The LH emits nominal power towards the OB; the optical power level is locked via the RIN control. The LH frequency is controlled via the Phasemeter.	0, 1, 4
8 (Amplitude modulation)	The optical power level of the LH emitted towards the OB is modulated with a frequency of 10 Hz. RIN and frequency noise performances are not met.	0, 1, 4

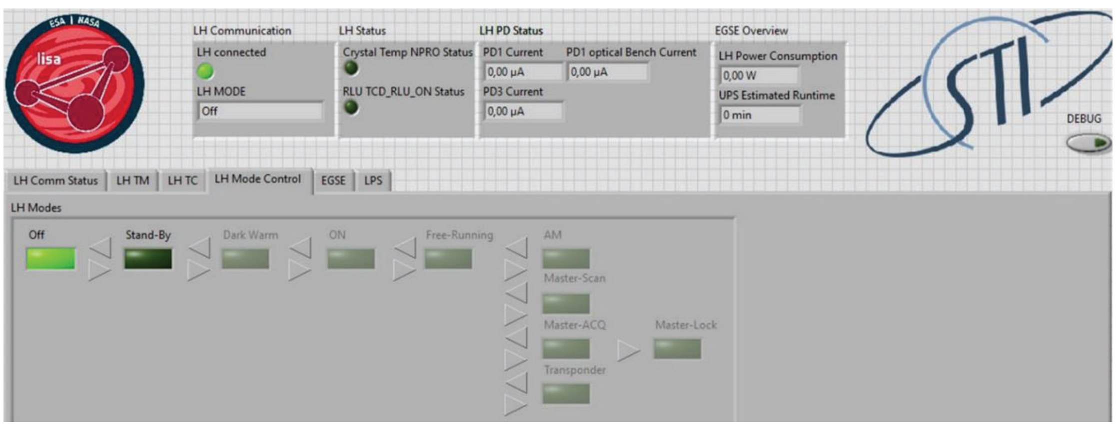

Figure 4. LabVIEW user interface to toggle between different operational modes of the LH. Bright green shows the current operational mode.

3. LASER COMPONENTS

The LH utilizes numerous electro-optical components. Single devices can be purchased as space-qualified components directly from the manufacturer. The majority of components are available as commercial of the shelf components only. They typically fulfil the Telcordia standard, i.e. they are tested for vibration, shock, and underwent thermal cycling test at ambient, but not in a vacuum environment and without radiation test. For the most part, the environmental loads (except for operational temperature[1]) do not match the loads for the components inside the LH or the manufacturer was not willing to provide sufficient details on the performed tests. Thus, it was concluded that environmental tests of most electro-optical devices against derived environmental loads are required. This work extends the scope of our activity, thus parts of the testing is contracted to two parallel ESA activities. Table 2 provides an overview of the environmental test planned per component. For each type of component, parts of two to three different manufacturers are tested.

[1] The expected operational temperature range within the LH is 10°C to 45°C for all components, based on thermal analysis of the EM and including margin. This is within the operational temperature limits defined in the data sheets.

Table 2. Overview of environmental tests on component level.

Component	Constructional analysis	Accelerated lifetime	Radiation	Thermal dissipation	Thermal cycling	Thermal vacuum	Vibration	Shock
Active fiber			X					
Band pass filter	X		X			X	X	X
Electro-optical modulator	X		X			X	X	X
Mode field adapter	X		X			X	X	X
Mode stripper	X		X	X		X	X	X
Optical isolator (high power)	X		X			X	X	X
Optical isolator (low power)	X		X			X	X	X
Optical switch	X		X			X	X	X
Photo diode	X		X			X	X	X
Pump combiner	X		X	X		X	X	X
Pump laser diode	X	X	X		X		X	X
Tap coupler	X		X			X	X	X

The accelerated lifetime and thermal vacuum tests are operational tests, whereas the others are non-operational. Depending on the component signal / pump light transmission, optical output power, isolation, output / transmission spectrum are testing before, after, and partly under test. The test campaign is ongoing. So far, we observed no abnormalities, see [7] for details.

4. LASER INTEGRATION AND TEST

The integration of the EM LH started in parallel to the component testing due to time constraints. Figure 5 depicts the optical power at the output of the first stage of a simplified fiber amplifier that was set up to ensure proper operation and matching of all components. The simplification covers the mechanical setup of the device. All mechanical and electronics parts are ready and all latter parts are integrated into the LH. The assembly of the electro-optical parts is ongoing and is accompanied by optical performance measurements, such as optical power, polarization extinction ratio (PER), and relative intensity noise (RIN). We plan to finish assembly in autumn 2022.

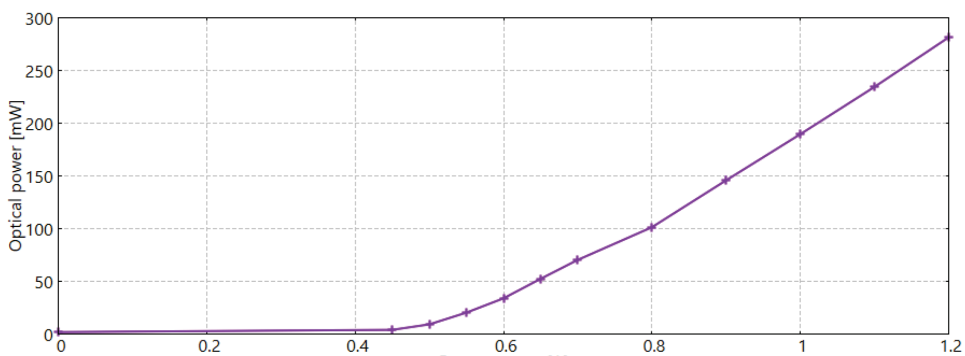

Figure 5. Optical power at the output of the first amplifier stage.

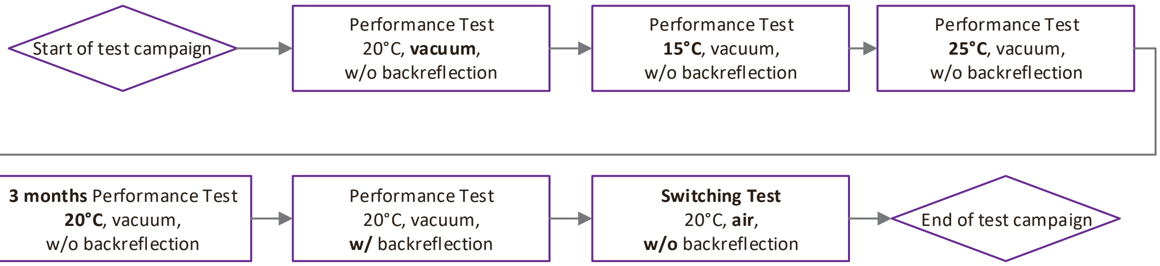

Figure 6. Flow diagram of the LH test campaign.

Subsequent to the assembly phase, a test campaign will start; see Figure 6 for an overview. We will set up the LH in a thermal vacuum chamber and operate it without any back reflection at three different temperatures (15°C, 20°C, 25°C) in vacuum. At each temperature, we will do a full set of optical performance measurements including optical power, PER, RIN, frequency stability (free-running and pre-stabilized to a cavity), spectral purity and many more. The planned duration for a performance test is one week per temperature. Next, a long-term test will start in which the LH is running, locked to a cavity, for three months. Followed by a performance measurement with back reflection and a switching test at ambient where the output light of the LH is toggled between the two optical output ports of the LH. The end of the test campaign is scheduled for early February 2023.

ACKNOWLEDGEMENTS

The activity “Gravitational Wave Observatory Metrology Laser” is funded by ESA, Contract No. 4000119715/17/NL/BW.

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