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FREQUENCY-STABLE SEED LASER FOR THE AEOLUS MISSION

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ABSTRACT

Coherent LIDAR systems require a frequency-stable and tunable seed laser source [1]. In general, a cw laser acts as an injection seeder for a Master Oscillator Power Amplifier system. The seed laser has to be a single-frequency source that can be tuned over several GHz in order to compensate for Doppler-induced frequency shifts of the return signal. For the ESA AEOLUS mission [2], Tesat-Spacecom has developed and flight-qualified a cw 1064 nm seed laser, the Reference Laser Head (RLH) for the high-power UV Doppler LIDAR instrument ALADIN [3]. Three RLH flight models (FMs) have been delivered. This paper details their design and performance data measured during development, qualification, and acceptance test campaigns. The lasers and laser diode pump modules are spin-offs of Tesat-Spacecom's development for inter-satellite coherent laser communication terminals [4].

1. REFERENCE LASER DESIGN

The RLH design is based on the separation of the basic requirements for frequency stability and frequency tunability. Therefore, the RLH encloses two 1064 nm lasers in one package (see Fig. 1). One single-frequency laser (RL) inside the RLH is frequency-locked to an optical reference cavity, the other one (SL) is locked to the stabilized RL by using a 10 GHz digital phase-locked loop (PLL).

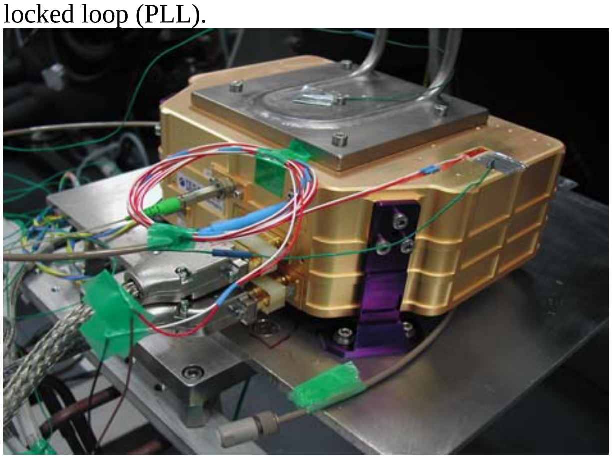

Fig. 1. ALADIN RLH FM23 mounted for IFT.

The basic parameters of the RLH are: Volume 2 liters, mass 2 kg, 20 W power consumption, 25 mW optical output power into a single-mode polarization-maintaining fiber, and frequency tuning range 8.333 GHz.

1.1 RL Loops

The 1064 nm emission from the RL is split into two outputs (see Fig. 2): One part of the light is used for locking the laser to a high-finesse optical cavity made from ULE glass, the other part is sent to the PLL assembly.

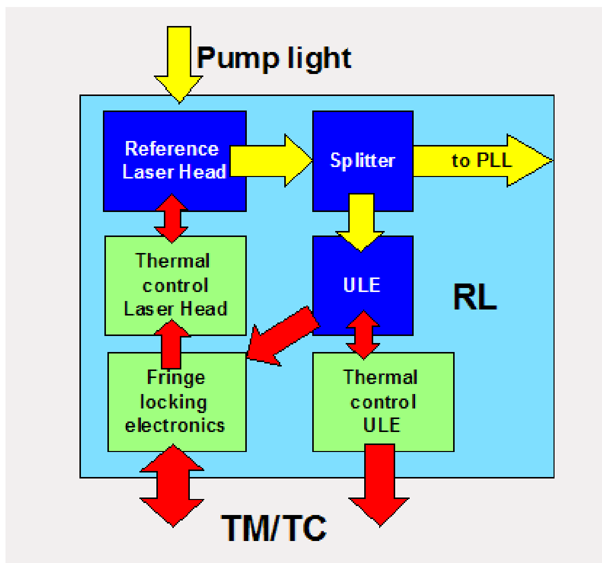

Fig. 2. RL design. Optical fiber connections are shown in yellow, electrical signals in red. TM/TC denotes telemetry and telecommand flows.

The RL is stabilized with respect to the optical reference cavity by fringe locking. The error signal from the locking electronics is fed into the frequency control of the laser, acting onto a fast frequency actuator (piezo) and a coarse thermal control loop. The thermal control of the cavity results in a ~10 mK temperature stability of the reference cavity from 13°C to 23°C environmental temperature.

1.2 SL Loops

The 1064 nm light from the SL laser is split into two parts (see Fig. 3): The majority is coupled to the Master Oscillator (MO; from Galileo Avionica S.p.A.), acting as the injection seed signal. A small part is combined with the RL light onto a fast (10 GHz) photo diode from Discovery Semiconductors, Inc., that has been qualified for space application in a dedicated test campaign. The beat signal detected by the photo diode is analyzed by the PLL. The PLL error signal is fed into the SL frequency control electronics. A Field-Programmable Gate Array (FPGA) handles the digital TM/TC interface to the customer and the programming of the PLL.

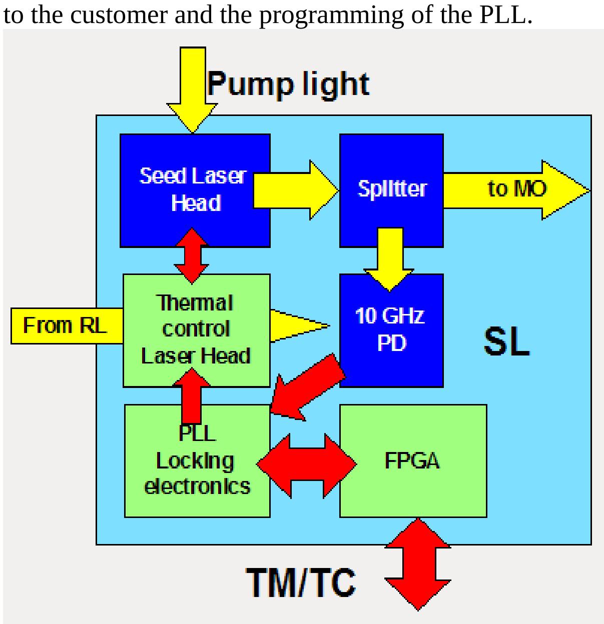

Fig. 3. SL design: Optical fiber connections are shown in yellow, electrical signals in red. TM/TC denotes telemetry and telecommand flows.

The PLL is externally programmable by a digital signal in 1000 steps of frequency separation between RL and SL. Each step corresponds to 8.333 MHz. This results in an overall stepping range of 25 GHz (after RLH-external frequency tripling) in the UV.

2. REFERENCE LASER TEST RESULTS

The three RLH flight models (FMs) were subjected to a test campaign that is based on the AEOLUS mission requirements. FM21 was tested in a PFM approach (QM levels and FM durations). FM22 and FM23 were subjected to FM acceptance tests. In addition, FM23 was subjected to a mechanical shock test. All tests were passed successfully. The FM23 acceptance test flow is shown in Fig. 4.

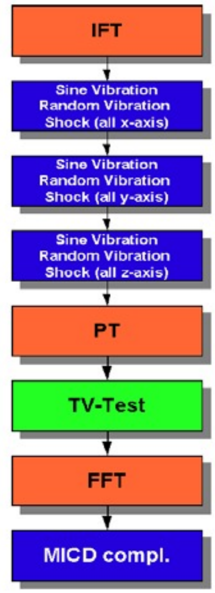

Fig. 4. FM23 acceptance test flow.

2.1 Line width, Frequency Stability and Stepping

The instantaneous line width of RLH FM23 was determined by beating a free-running Mephisto 1064 nm single-frequency laser from InnoLight GmbH with RLH FM23. FM23 demonstrated an instantaneous FWHM line width of 7 kHz (requirement: < 10 kHz).

The frequency stability of the RLH is dominated by the frequency stability of the optical reference cavity including the thermal stabilization and frequency locking electronics. It is approaching 2×10^{-11} Hz/Hz at 1000 s (see Fig. 6).

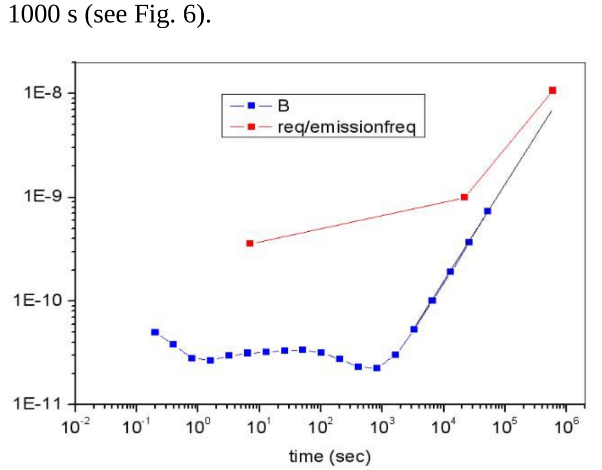

Fig. 6. Allan variance (in Hz/Hz) of the RL cavity (blue) compared with the AEOLUS mission requirements (red).

A frequency stability measurement (beat against Iodine-cell-stabilized Nd:YAG laser) showed center frequency deviations of 15 kHz rms over 7 s (requirement:

< 100 kHz rms over 7s) and 21 kHz rms over 100 s. The center frequency of the RLH drifts at 110 kHz/K when the cold plate temperature is changed between 14.0°C and 16.2°C at 8 K/h.

The frequency agility of the RLH was measured repeatedly during the FM tests. These tests consist of 1000 steps with 8.333 MHz frequency separation and 250 ms timing (“fine stepping”), or of 100 steps at 83.33 MHz in a 950 ms stepping sequence (“large stepping”). To determine the actual frequency separation between RL and SL, the PLL input signal (i. e. the beat signal between RL and SL) is measured using a frequency counter from Agilent Technologies (HP53131A with 12.4 GHz bandwidth) during step tuning. This frequency counter is read out at approximately 40 Hz. The difference frequency resolution is 10 kHz. Both the fine and the large stepping scheme will be used for the ALADIN receiver calibration. Two results are shown in Fig. 7 and Fig. 8. A commanded 3.4 GHz jump of RL-SL frequency separation is executed in less than 2.5 s (see Fig. 9).

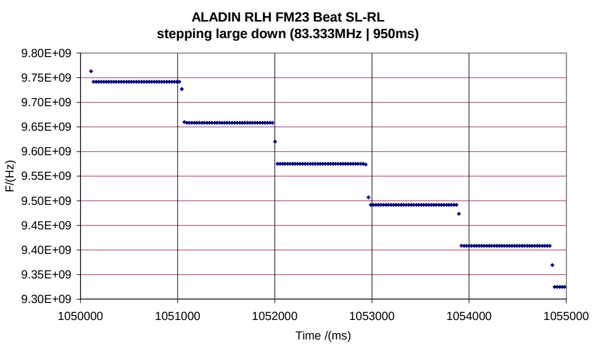

Fig. 7: Frequency stepping verification “large down”. Only a small portion of the duration of the experiment is shown.

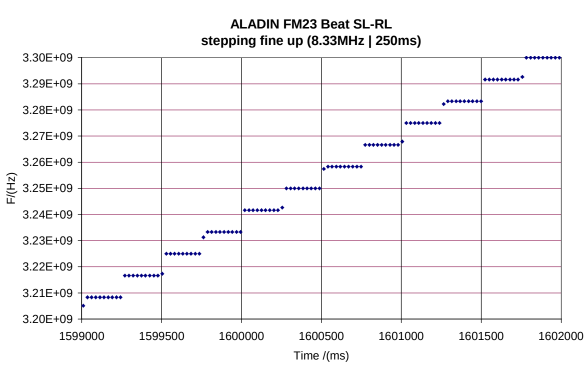

Fig. 8. Frequency stepping verification “fine up”. Only a small portion of the duration of the experiment is shown.

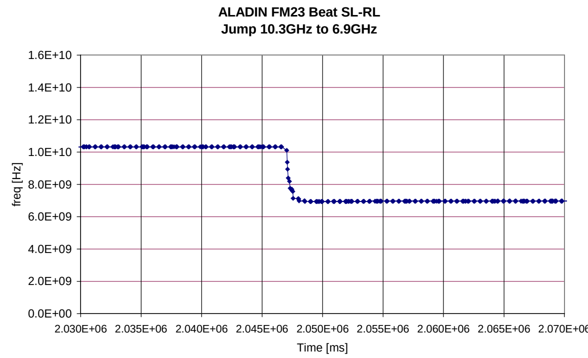

Fig. 9. 3.4 GHz jumping verification of SL-RL beat signal.

3. SUMMARY

This paper presents the design and performance of the ALADIN RLH, to be used in the ESA AEOLUS mission. Three FMs have been delivered. Their frequency stability and tunability requirements were met with margin in a space-qualified compact setup. The flexible digital interface for the frequency command can adapt to different tuning requirements (larger or smaller step sizes, different stepping sequences) for other possible missions. Recently, Tesat-Spacecom has been contracted to deliver two further ALADIN RLHs for ATLID, ESA's atmospheric LIDAR program. The ATLID instrument is foreseen for the EarthCARE satellite and designed primarily to provide satellite measurements of cloud-top height both day and night and aerosol profiles.

4. REFERENCES

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