International Conference on Space Optics—ICSO 2014

La Caleta, Tenerife, Canary Islands

7–10 October 2014

Edited by Zoran Sodnik, Bruno Cugny, and Nikos Karafolas

Qualification testing of fiber-based laser transmitters and on-orbit validation of a commercial laser system

M. W. Wright

M. W. Wilkerson

R. R. Tang

International Conference on Space Optics — ICSO 2014, edited by Zoran Sodnik, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 10563, 1056338 · © 2014 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2304100

QUALIFICATION TESTING OF FIBER-BASED LASER TRANSMITTERS AND ON-ORBIT VALIDATION OF A COMMERCIAL LASER SYSTEM

M. W. Wright[1], M. W. Wilkerson[1] and R. R. Tang[2]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA . [2]Nuphoton Technologies, Inc, Murrieta, CA 92562, USA
malcolm.wright@jpl.nasa.gov

ABSTRACT

Qualification testing of fiber based laser transmitters is required for NASA's Deep Space Optical Communications program to mature the technology for space applications. In the absence of fully space qualified systems, commercial systems have been investigated in order to demonstrate the robustness of the technology. To this end, a 2.5 W fiber based laser source was developed as the transmitter for an optical communications experiment flown aboard the ISS as a part of a technology demonstration mission. The low cost system leveraged Mil Standard design principles and Telcordia certified components to the extent possible and was operated in a pressure vessel with active cooling. The laser was capable of high rate modulation but was limited by the mission requirements to 50 Mbps for downlinking stored video from the OPALS payload, externally mounted on the ISS. Environmental testing and space qualification of this unit will be discussed along with plans for a fully space qualified laser transmitter.

I. INTRODUCTION

The development of laser transmitters for future space based operational optical communications systems requires an extensive investment in demonstrating the reliability of the technology from the component to the assembly level due to the harsh launch and space environment requirements. Previous work showed that commercial-off-the-shelf (COTS) laser systems are able to survive typical NASA environmental requirements, for example the General Environmental Verification Specifications (GEVS) requirements for mechanical robustness [1]. Several systems were tested and survived a select test protocol [1], demonstrating the maturity and robustness of the technology. This robustness is brought about by virtue of using fiber based laser transmitters as the communication source, thus leveraging the terrestrial telecommunications investment of this technology due to the similar performance and even environmental requirements. Additional environmental requirements necessary to perform in the space environment, include vacuum compatibility, levels of shock testing and thermal cycling and radiation hardening.

As a precursor to a fully space qualified operational system, a low cost laser transmitter was developed as part of a technology demonstration experiment (Optical Payload for Lasercomm Science or OPALS) to fly as an external payload on the International Space Station (ISS) [2]. Technology demonstration missions provide a low cost approach to the development and deployment of new technologies for future mission opportunities. Optical communications is a key technology targeted by NASA to improve the science data return for high capacity science instruments. Similar to the architecture of a deep space laser transmitter with the exception of the ability to support high peak powers, the master oscillator power amplifier (MOPA) laser supported moderate data rates up to several hundred Mbps with on-off keyed (OOK) modulation format or low order pulse position modulation (PPM), up to $m = 16$, with 2.5 W of average power at 1550 nm. The actual implementation focused on just OOK due to the ground receiver constraints and was limited to 50 Mbps. The unit was deployed in a pressure vessel along with the COTS avionics in keeping with project guidelines even though vacuum compatibility has been shown for other commercial or space grade laser systems [3]. The output of the laser was fiber routed through a vacuum compatible feed-through to the gimbaled optical head where it was transmitted with a 1.5 mrad beam divergence. The environmental requirements were derived from the mission requirements in conjunction with previously developed lasers for other terrestrial applications. No radiation requirement was levied due to the short mission duration of 90 days.

It should be noted that other laser transmitters have been deployed on spacecraft in optical communication systems [4,5,6] and operated successfully though long term reliability has not been demonstrated yet. The focus of the current project was to demonstrate the ability of a commercially packaged laser to meet the mission requirements, using COTS components only without any custom parts testing or upgrades. Future mission opportunities, especially for deep space systems, require a fully space qualified approach for the laser transmitter development. A full qualification plan would then require component level screening and testing, extensive environmental testing of the assembly with engineering and qualification models prior to a flight or proto-flight unit development. Such a program was beyond the scope of the current project.

The first section describes the experimental approach and the laser design based on the commercial product line. The next section describes the assembly level tests and results with further system leveling testing occurring once the laser is integrated into the OPALS terminal. Finally we will discuss the implication of these results on future mission opportunities.

II. EXPERIMENTAL APPROACH

A. Laser Design

The key performance requirements are listed in Table 1 below:

Table 1 Laser Performance Requirements.

Parameter	Value	Comment
Average Power, W	2.5	2.0 EOL
Peak Power, W	20	
Center Wavelength, nm	1550	+/- 0.1
Linewidth, nm	< 0.1	
Optical SNR loss, dB	< 0.25	in 0.1 nm
Pulse Rep. Freq (PRF), MHz	1 – 400	
Duty Cycle, %	12.5 - 50	
Pulse Extinction Ratio, dB	> 15	
Pulsewidth, ns	2.5 - 500	
Pulse Jitter, ps	< 35	
Output Beam Quality	< 1.2	SMF, opt. isolated
Polarization	None	
Power required	< 50 W	28 V supply
Pump light leakage, µW	< 100	
Dimensions	compact	OEM type module

The MOPA laser is based on a product line of multi-Watt MOPA fiber based lasers, ruggedized to meet demanding field applications and is shown in Fig. 1. A semiconductor DFB seed laser was directly modulated and followed by a two stage fiber amplifier. Telcordia certified components were required to the extent possible along with hermetically sealed laser diodes. Monitor and control was performed through the RS422 interface with hardware A/D ports for monitoring output power of each stage and temperatures of the diode lasers as well.

B. Environmental Requirements

Since the laser was based on a commercial design and operated in a forced air-cooled pressure vessel, vacuum compatibility and additional thermal management were not required. This relaxed the environmental requirements which are listed in Table 2 below and were obtained from a combination of JPL workmanship levels and the vendor input. The product line from which the delivered unit was derived has undergone significant reliability testing, similar to the specifications in Mil Std-810E, and gave confidence that the environmental requirements could be met. This testing is shown as the heritage column of Table 2.

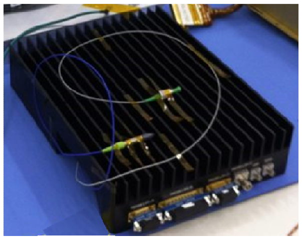

Fig. 1 Laser Transmitter showing interface and cooling fins on the base.

Table 2 Environmental Requirements

Test	OPALS Qualification Level	Heritage Qualification Level
Mechanical Shock	40 g 3 ms, twice Each axis	25 g 11 ms, 3 x Each axis
Vibration	20 Hz @ 0.0216 g^2/Hz 30 – 750 Hz @ 0.046 g^2/Hz 830 Hz @ 0.025 g^2/Hz 2000 Hz @ 0.01 g^2/Hz 7.53 g_{RMS} overall	20 Hz @ 0.0216 g^2/Hz 30 – 750 Hz @ 0.046 g^2/Hz 830 Hz @ 0.025 g^2/Hz 2000 Hz @ 0.007 g^2/Hz 6.9 g_{RMS} overall
Thermal Cycle	-10 to +65 °C non-operational, 10 x 0 to +55 °C operational, 10 x 10 min dwell, 2.5° C/min	0 to +50 °C operational, At 5° C steps with 10 min at each step
Vacuum Compatibility	n/a– operated at 1 atm	-
Radiation	none	-
Outgassing	none	-
EMI/EMC	EN 61326, EN 55011 Emissions Group 1, Class A	-
Life Test	3000 Hrs – by design	-

III. RESULTS AND DISCUSSION

A. Thermal Analysis

Thermal analysis was done on the unit up to a maximum ambient temperature of 45° C when the laser was operated at full power of 2.5 W. An example of the simulation is show in Fig. 2 where the temperature rise is limited to 70° C at the pump diode mounting location. The individual pump diodes have been tested to 85° C separately so this should not be an issue. The forced airflow would mitigate any further temperature rise.

B. Unit Ground Testing

Unit testing by the vendor was limited to the vibration, shock and temperature cycling tests specified in Table 2. Before and after testing showed no degradation in the power or output spectra with post-testing representative spectra shown in Fig. 3.

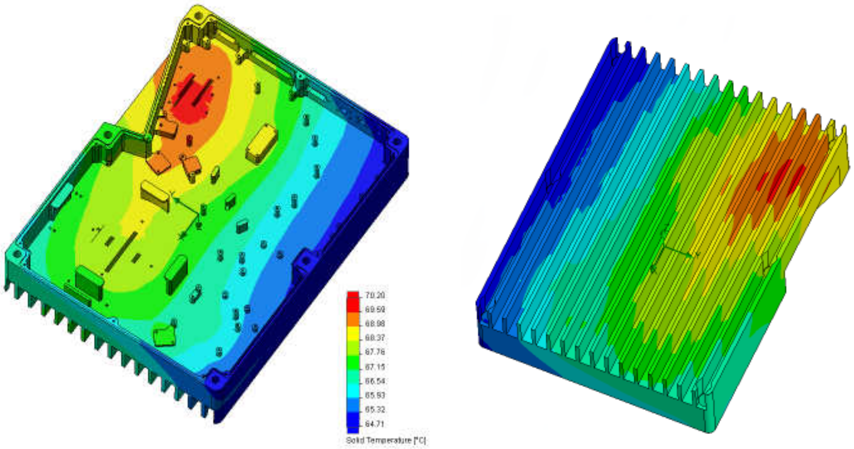

Fig. 2 Laser Transmitter thermal simulation with 45° C ambient temperature at full power.

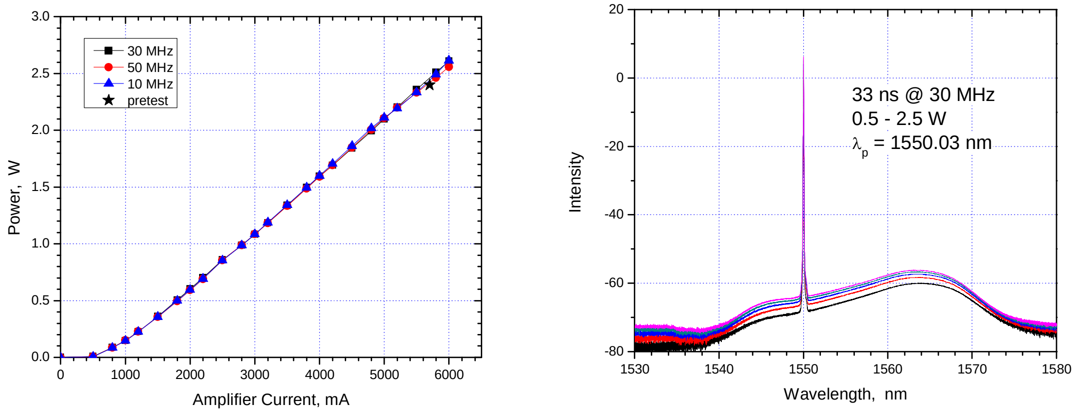

Fig 3. (a) Average power before and after testing at various PRFs, and (b) wavelength spectra post testing for laser under fixed PRF.

Temperature cycling from 0 to 50^o C was performed while the device was operated at full power with 5 cycles at 30 MHz and 5 cycles at 50 MHz. The output power over the several hours of testing is shown in Fig 4 and shows very good stability.

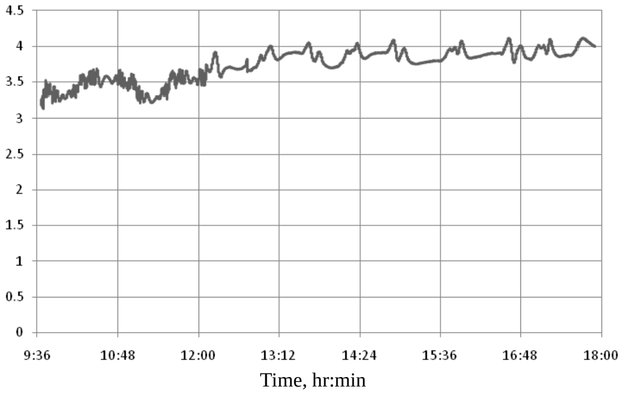

Fig. 4 Laser Transmitter output power (tapped power in dBm) stability as a function of time. Up to 12:10 pm the laser was operated at fixed current to give 2.4 W output and up to 18:00 it was operated at fixed power of 2.5 W.

C. System Level Ground Testing

The laser was first integrated to the component tray assembly, itself mounted on wire rope isolators that provide vibrational attenuation of the sensitive components. The sealed container element was completely integrated prior to initiation of the system environmental test regime. Once integrated into the pressure vessel, Fig 5, the instrument was subjected to further system level environmental tests. Tests that were performed and were given to affect the performance of the laser were three axis system vibe and a five day thermal vacuum test. Functional testing of the system was performed at key points during the vibrational tests. The results are shown in Table 3. All measurements are assumed to include a 1 dB insertion loss of the fiber connectors. No degradation in laser performance was observed nor of the optical path for the laser output.

For the full flight system thermal vacuum test, the payload was run to hot and cold temperatures at the proto-qualification level above the allowable flight temperatures to demonstrate survivability and functionality at the extremes of the expected temperature. The allowable flight temperatures were 10 to 45^o C for operations and 5 to 50^o C for non-op and the proto-qualification temperature ranges were 5 to 50^o C and -10 to +65^o C for

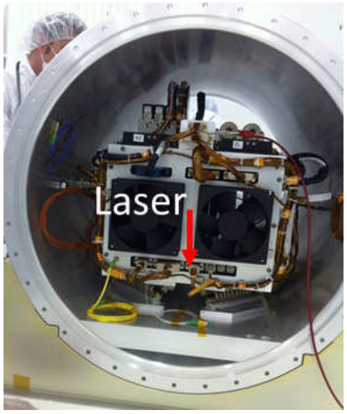

Fig.5 Laser Transmitter mounted in pressure vessel below circulating fans.

operation or non-op, respectively. Laser measurements were taken at the collimator output with temperature measurements from externally mounted thermocouples as well as the internal laser monitor points during laser operation. For test success, hot qualification had to operate the laser unit at the hot op proto-qualification value, but without emitting light. The cold qualification was successful if the laser unit was operated at the cold proto-qualification temperature but while emitting light at full power. Hot and cold non-op dwells were also performed, but the laser unit was not powered at this time. All tests were completed successfully.

Table 3 System environmental test results.

Test	Measured Output Avg. Power (ex-Collimator), W	Comment
Pre-Vibe Test	1.9	+/- 0.1
Post-VibeTest: X-axis	2.006	
Post-VibeTest: Y-axis	2.065	
Post-VibeTest: Z-axis	2.05	

D. On-Orbit Operations

The OPALS instrument was launched April 18th on an ISS resupply mission in the trunk of the SpaceX Falcon 9 Dragon capsule and commissioning activities began once it was installed on the ELC rack of the ISS on May 10th. The laser was powered on successfully and has operated for over 15 link demonstrations. Each link opportunity typically lasts for 2.5 min for the LEO orbiting ISS over the ground station with the laser powered on to 2.5 W of full power for approximately 10 min before the pass for stabilization. Sample monitor data from the laser telemetry are shown below for a single link on-orbit and show no degradation in performance from the initial ground testing, also shown in the graph for the pre-vibe system testing, taken a year and a half earlier.

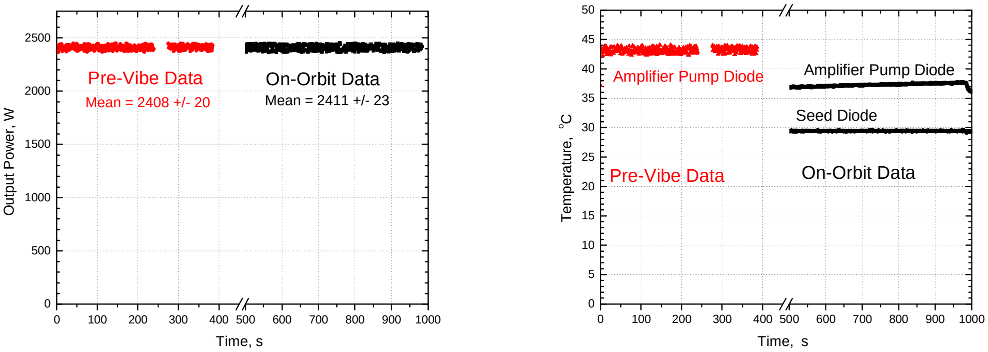

Fig. 6 Test data during operations compared to pre-vibe ground test data (a) monitor power, (b) monitor temperatures. Similar time frames are shown for each test, taken 1.5 years apart.

During laser operations the seed temperature is kept at approximately 29° C and the amplifier pump diode temperature is on the order of 37° +/- 0.5° C.

The successful operation on-orbit of the commercial laser transmitter points to the robustness of the component and assembly level technology that is derived from Mil-Std and Telcordia design and test practices used in the fiber telecommunications industry. Long term reliability still needs to be investigated for operational space based optical communication systems. This will be addressed under a program requiring full space qualification of each assembly which is ongoing. However, given the successful performance of the current system, the present work provides a good baseline for the part selection of this future program. It should also be noted that some space programs require a rapid delivery response for instruments that might not be compatible with the test and development times of a fully space qualified system. Integrating COTS parts in an air-cooled pressure vessel could be envisioned as a way to provide the capability without the long lead times of a fully space qualified design and test program.

IV. CONCLUSION

The OPALS experiment has demonstrated the robustness of low cost commercial technology for a laser transmitter designed for space borne free space optical communications. The laser was subjected to a nominal qualification test protocol compared to that required for a full space qualification program and has operated successfully on the ISS platform in LEO orbit for over 15 link opportunities of approximately 15 min each.

V. ACKNOWLEDGEMENTS

This work described was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology under contract with the National Aeronautics and Space Administration (NASA).

REFERENCES

[1] M. W. Wright and H. Hemati, "Pulsed fiber amplifiers in simulated space environmental tests", *Proc. SPIE vol.* 8971-10, 89710B, San Francisco, CA, Feb 2014; doi:10.1117/12.2045102

[2] B.V. Oaida, W. Wu, B.I. Erkman, A. Biswas, K. Andrews, M. Kokorowski, M. Wilkerson, **"**Design and validation testing of the optical link of the Optical Payload for Lasercom Science (OPALS) system", *Proc SPIE* 8971-31 San Francisco, CA, Feb 2014

[3] M.W. Wright, A.B. Piccirilli, and A.R. Grant, "Preliminary results of testing a space-grade laser transmitter for optical communications," *Proc. SPIE* 8246, 82460L (2012)

[4] Z. Sodnik, L. Hanspeter, F. Bernhard, R. Meyer, "Optical satellite communications in Europe", *Proc SPIE* 7587, 758705 (2010) doi 10.1117/12.847075

[5] Y. Fujiwara, M. Mokuno, T. Jono, T. Yamawaki, K. Arai, M. Toyoshima, H. Kunimori, Z. Sodnik, A. Bird, B. Demelenne, " Optical inter-orbit communications engineering satellite (OICETS)", Acta Astronaut 61, 161-175 (2007)

[6] D.M. Boroson, B.S. Robinson, D.V. Murphy, D.A. Burianek, F. Khatri, J.M. Kovalik, Z. Sodnik, "Overview and results of the Lunar Laser Communication Demonstration," *Proc SPIE* 8971-10 San Francisco, CA, Feb 2014