

Overview of the LISA Laser System Main Oscillator Development

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ABSTRACT

Avo Photonics has been contracted by NASA to design, develop, and manufacture the Main Oscillator (MO) seed laser for the ESA-led LISA (Laser Interferometer Space Antenna) mission [1]. An overview of the design and test results will be presented in this paper. The LISA mission is a space-based gravitational wave detection system slated to launch in 2035. The LISA mission will build on measurements already collected by ground-based gravitational wave detection systems such as LIGO (Laser Interferometer Gravitational Wave Observatory), but with a reduced noise floor, allowing for detection of waves with frequencies as low as 0.1 mHz. The MO is a critical component of the full LISA Laser System being developed by NASA. It serves as the seed laser for LISA's interferometer operation. As such, minimizing intensity noise and frequency noise was an imperative consideration in Avo's design. To achieve this, the MO utilizes a diode-pumped micro-non-planar ring oscillator laser, which has been proven to meet the LISA mission's stringent noise requirements. Reliability is also paramount, and the design has incorporated elements of ruggedness and redundancy to address this. Recently, Avo Photonics has manufactured 24 engineering models of the MO. These units underwent performance testing and limited qualification testing at our facility, including thermal cycling, power characterization, and noise testing. Select units were delivered to Goddard, where they underwent a complete qualification regimen including shock and vibration, radiation, and thermal vacuum testing. The results of these tests showed that the units successfully meet the specifications required for the LISA mission.

Keywords: LISA, seed laser, main oscillator, ultrastable

1. INTRODUCTION

The LISA mission is a space-based gravitational wave detection system slated to launch in 2035 [1]. The system will be composed of three satellites which form a tri-armed interferometer. Path length perturbations on the order of picometers that are induced by gravitational waves will be detectable by the system. This allows for many scientific use cases such as detecting black hole merger events, characterizing distant galaxies with extreme mass ratio inspirals, and exploring the onset of cosmic structure formation [1]. The LISA mission will build on measurements already collected by ground-based gravitational wave detection systems such as LIGO, Virgo, and KAGRA [2] but with a reduced noise floor, allowing for detection of waves with frequencies as low as 0.1 mHz.

NASA Goddard Space Flight Center (GSFC) has partnered with the European Space Agency (ESA) to develop the Laser System (LS) for LISA. Figure 1 shows the architecture of the LS within one (1) spacecraft [3]. Each spacecraft contains one (1) LS which will communicate with the two other spacecraft used for the mission. Each LS contains four (4) Laser Heads (LH), two of which are included for redundancy. The LH contains a Laser Optical Module (LOM), which is composed of a Phase Modulator, a Power Amplifier, and the Main Oscillator (MO) seed laser that Avo Photonics (Avo) has been contracted to design, develop, and manufacture.

Figure 2 shows the performance requirements for the MO that were provided to Avo by GSFC. These requirements informed Avo's optomechanical design and the testing suite that each unit must undergo prior to delivery. Notable specs are high output power (400 mW), fast frequency tuning (> 11.2 MHz/V), low relative intensity noise (RIN), and frequency noise down to a frequency domain of 0.1 mHz. In addition to these well-defined requirements, the need for ruggedness and redundancy was emphasized at the design onset.

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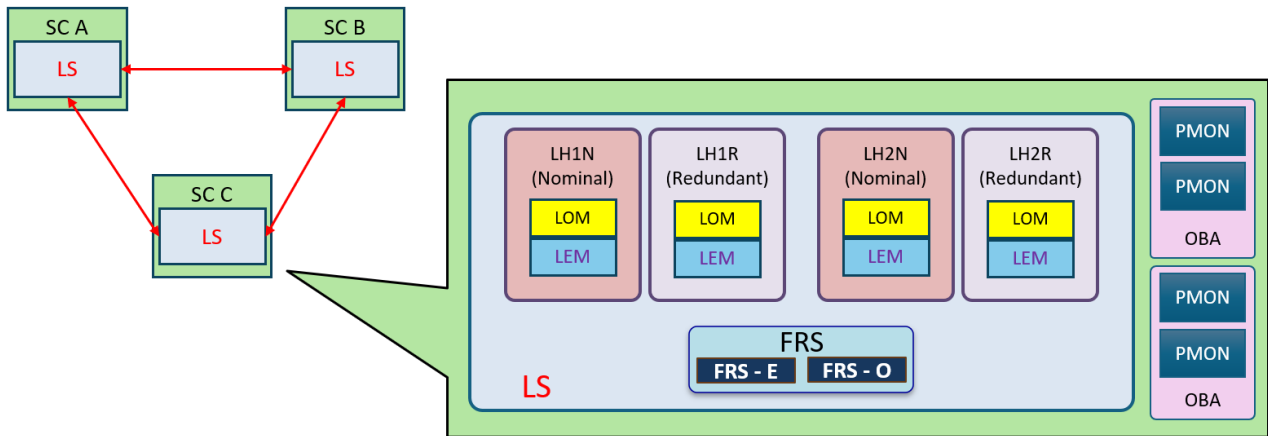


Figure 1 - LISA laser system architecture.

Optical	Min	Nominal	Max	Units
Wavelength	1064.45	1064.5	1064.55	nm
Fast Actuator Tuning Coefficient	11.2		16.8	MHz/V
Rated Output Power		200		mW
Output Power (Kink-Free)	400			mW
Output Mode	TEM00			n/a
Operating Current - Both Pumps at Rated Output Power		300	400	mA
Operating Current - Pump 1 at Rated Output Power		600	800	mA
Operating Current - Pump 2 at Rated Output Power		600	800	mA
Pump Diode MPD Signal at Rated Output Power	0.1		0.2	mA
Output MPD Signal at Rated Output Power	1.8		2.7	mA
Output PER	18	20		dB
Output Polarization	Slow Axis			n/a
Fiber Facet Angle, Input Side	7.5		8.5	°
Stability				
Relative Intensity Noise				
	0.1 mHz - 100 Hz	$< 1E-04 * \sqrt{1 + (0.5E-03 / f)}$		1 / sqrt(Hz)
	100 Hz - 3 MHz		2.00E-06	1 / sqrt(Hz)
	3 MHz - 3 GHz		3.00E-08	1 / sqrt(Hz)
Frequency Noise (0.1 mHz - 1 Hz)	$< 3.75 * \sqrt{1 + (8 \text{ kHz}/f)^2}$			Hz / sqrt(Hz)
Power Consumption				
Power Consumption at Rated Operation		0.8		W
Mechanical				
Hermeticity (Fine Leak Rate)			1.00E-08	cc/s (Air, std. P)
Package Weight		0.173	1.1	kg
Package Size (excl. pins & fiber)		68 x 54 x 14		mm
Mounting Feet	3.21	3.26	3.31	mm
Mounting Points		3		n/a
Package Flatness			50	µm
Environmental				
Operating Lifetime	6.5			Years
Operating Temperature	15	20	25	°C
Storage Temperature	-30	25	50	°C

Figure 2 - Main Oscillator performance specifications.

2. MO DESIGN

The primary lasing component of the MO is a micro-non-planar ring oscillator (μ NPRO) crystal which emits 1064 nm laser light that is ultrastable in both relative intensity noise (RIN) and frequency [4]. The crystal is pumped using two (2) pump diodes, although the output power specification can be met using a single pump diode. The decision to use both pump diodes during nominal operation allows for significant derating, often referred to as a “warm redundant” architecture. The wavelength emitted by the crystal falls within 1064.5 ± 0.05 nm and is adjustable via both a slow actuator and fast actuator mechanism [5]. Figure 3 shows a diagram of the laser’s optical path within the μ NPRO and an image of the front facet collected during optical alignment. Both the pump diodes and the μ NPRO crystal are independently temperature-controlled, and the temperature control mechanisms contain elements of redundancy that minimize the risk of component failure. The MO also contains three (3) internal power monitors, one each for the two pump diodes and one for the total output power. These power monitors serve to improve control of the MO’s output power stability and provide diagnostic information of the internal function of the MO.

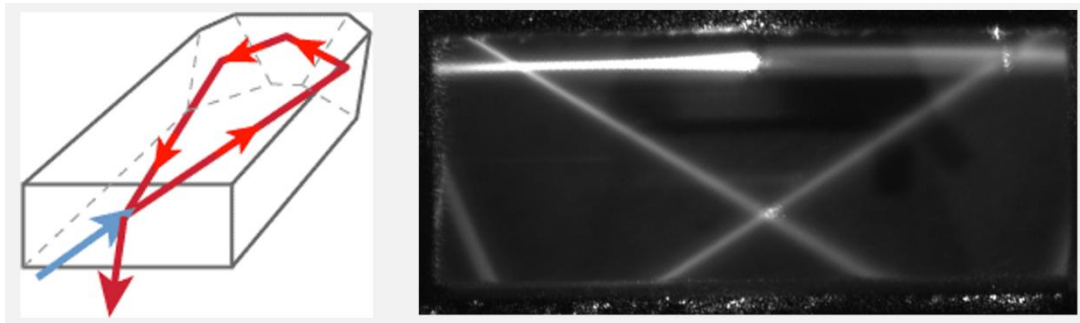


Figure 3 - Micro-Non-Planar Ring Oscillator. Diagram of optical path (left) [4] and image collected during alignment of MO (right).

The MO packaging is hermetically sealed with a dry air internal environment. To reduce the risk of hydrocarbon contamination, getter is included within the package, and flux-free solder bonds are utilized for as many components as is feasible. The package is compact (approximately 5 x 6 x 1.5 cm) and lightweight (approximately 0.2 kg). The package’s dimensions and thick base minimize the risk of flexure during mounting and operation. Figure 4 shows a portion of the mechanical interface drawing of the MO

The optical output of the MO is transmitted through a polarization-maintaining single mode fiber. The polarization extinction ratio always meets the 18 dB requirement, while typical values are around 25 dB. The MO can meet all performance specifications up to 400 mW output power. Figure 5 shows an image of the fully assembled, fiber-coupled MO.

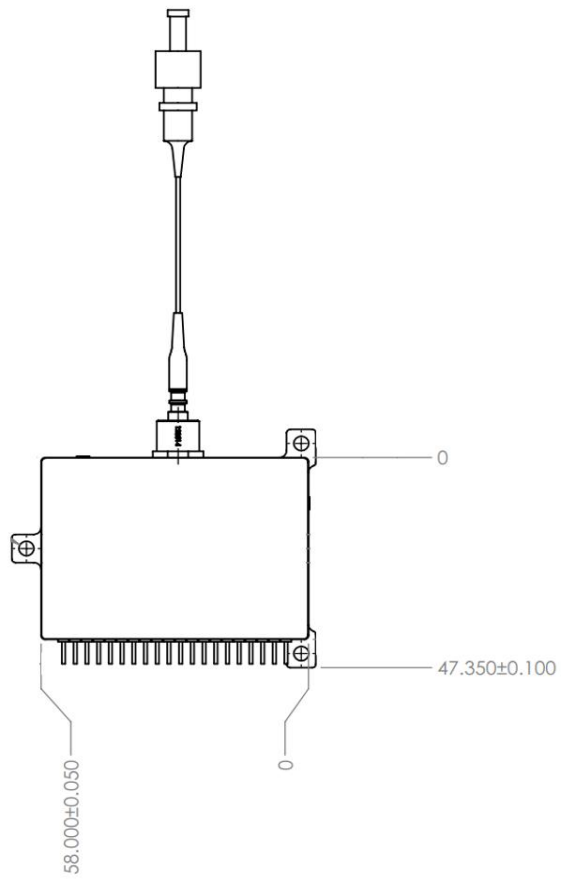


Figure 4 - Main Oscillator mechanical interface drawing.



Figure 5 - Fully assembled Main Oscillator.

3. PERFORMANCE TEST RESULTS

Recently, Avo manufactured 24 Engineering Models (EM) of the MO and delivered them to GSFC. These units underwent functional testing at Avo and GSFC and results from both tests are described in this section.

Figure 6 shows a plot of the output power of the MO at varying pump drive currents when both pumps are driven simultaneously (green trace) and when the pumps are operated individually (orange and blue trace). The plot displays different data series for operation using both pumps simultaneously and each pump individually. The EM unit meets the dual-pump kink-free output power spec of 400 mW. The data also shows that an individual pump can achieve 200 mW output power at less than 800 mA drive current.

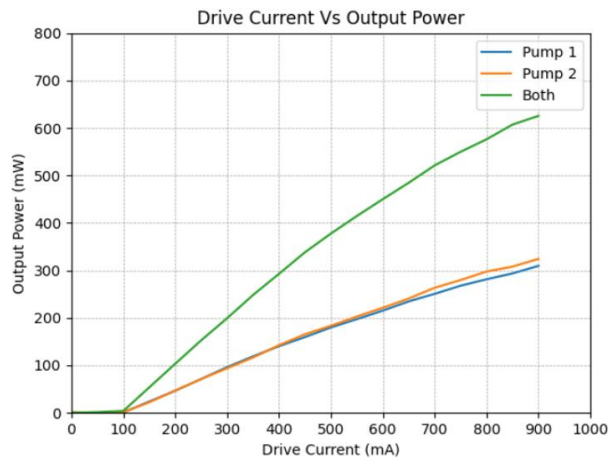


Figure 6 - Main Oscillator LI curve.

Figure 8 and Figure 7 show the internal power monitor signals at varying pump drive current. As shown by the plots, the MO meets both the pump power monitor signal and output power monitor signal specifications (0.1 – 0.2 mA and 1.7 – 2.8 mA at 200 mW output power, respectively).

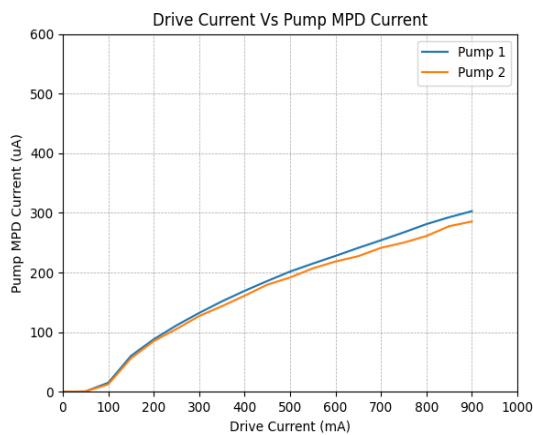


Figure 8 - Pump power monitor signal vs. drive current.

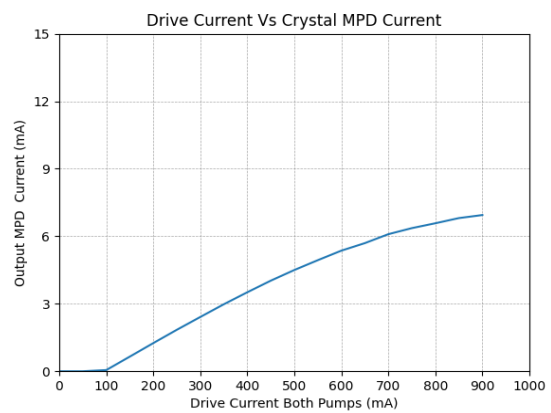


Figure 7 – Output power monitor signal vs. drive current.

RIN testing was also performed at Avo, as shown in Figure 9. The EM unit meets the RIN requirements in the frequency range of 100 kHz to 3 MHz. Both RIN and frequency noise are tested across the entire frequency range of interest by GSFC. Results shown in Figure 10 demonstrate that the MO meets both noise specifications.

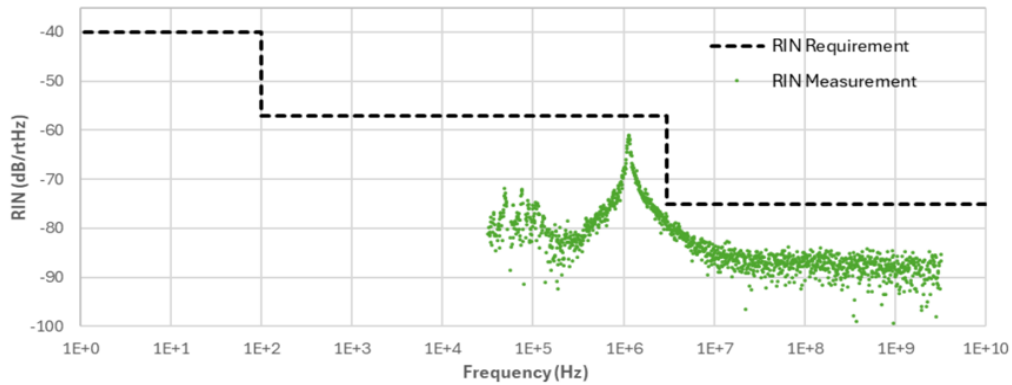


Figure 9 - Measured RIN spectrum of MO.

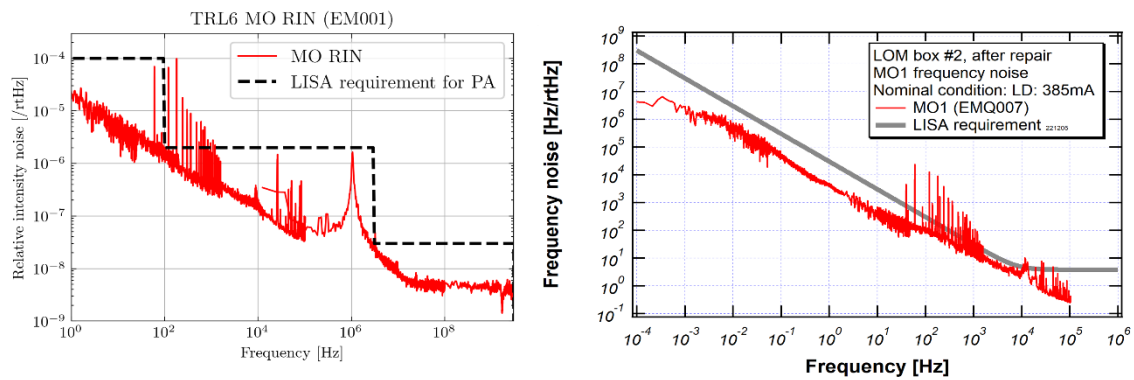


Figure 10 - RIN (left) and frequency noise (right) of the MO measured by NASA GSFC.

The fast frequency tuning coefficient was also characterized by GSFC. Representative test data shown in Figure 11 demonstrates that the EM MOs have a tuning coefficient of 13.96 MHz/V, meeting the requirement of 11.2 – 16.8 MHz/V.

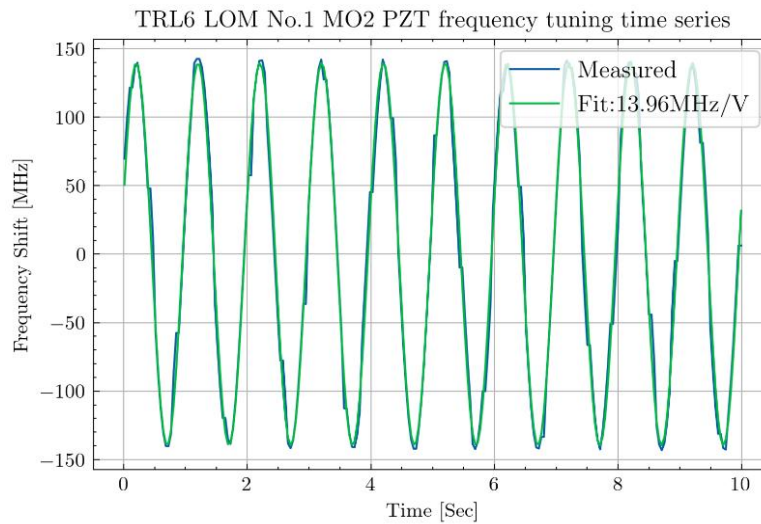


Figure 11 - Fast frequency tuning performance data collected by NASA GSFC.

4. RELIABILITY TEST RESULTS

The EM MOs underwent environmental qualification testing at GSFC after delivery. Those test results will be described in this section.

GSFC performed temperature cycle testing on the EM units across the non-operational temperature range at ambient air atmospheric pressure. No changes were observed in any performance metrics across the temperature sweep. These metrics include output power, internal monitor signals, wavelength, RIN, and frequency tuning coefficient. The RIN test results are shown in Figure 12.

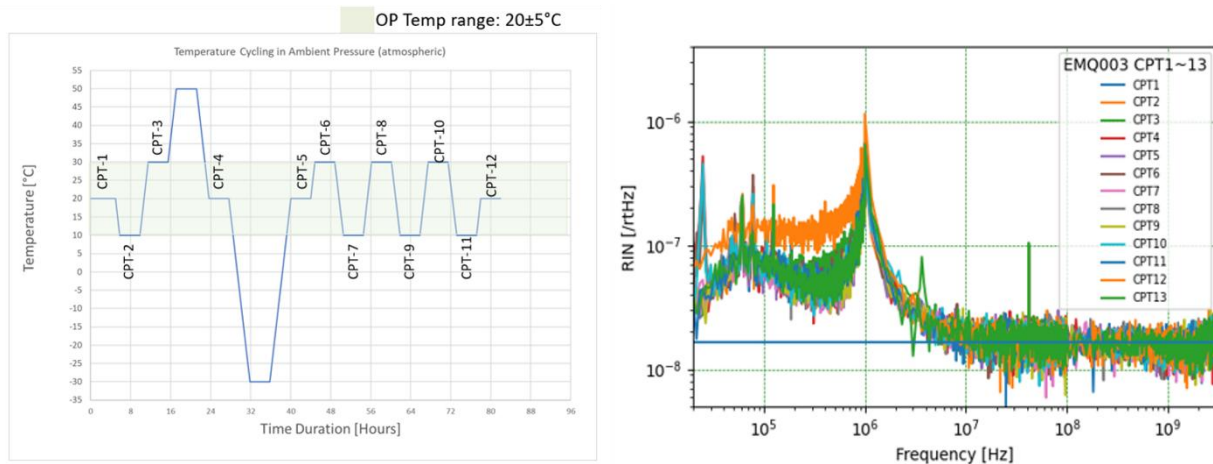


Figure 12 - Temperature cycle test results of the MO EM model. Temperature ramp program is shown on the left, and corresponding RIN spectra are shown on the right.

GSFC also performed shock and vibration testing on the EM units. The units were tested to General Environmental Verification Standard (GEVS) levels for each test. There were no significant changes observed in any performance metrics after the exposure. The output power results before and after exposure are shown in Figure 13.

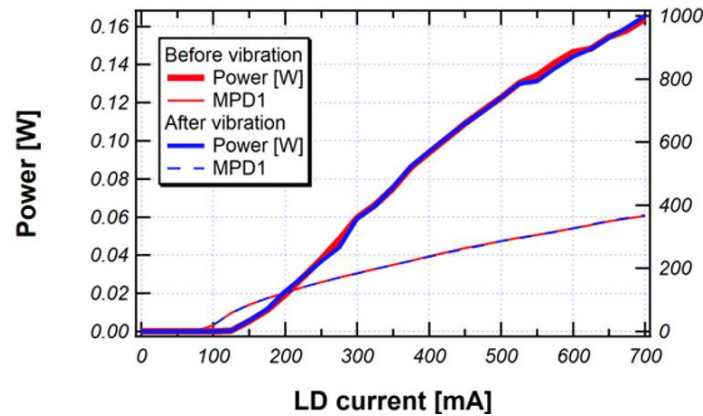


Figure 13 - Shock/vibe test results of the MO EM model. Output power pre/post exposure is shown.

The EM units also underwent radiation testing at GSFC. The units were exposed to 40 krad of gamma radiation, and their performance was characterized before and after the exposure. There were no changes in RIN, frequency noise, frequency tuning coefficient, and internal power signals. The noise results are shown in Figure 14. The units did show a 10% drop in output power after exposure, which is believed to be caused by optical component darkening. This power loss is recoverable with increased pump drive current while still maintaining derating of the pump diodes.

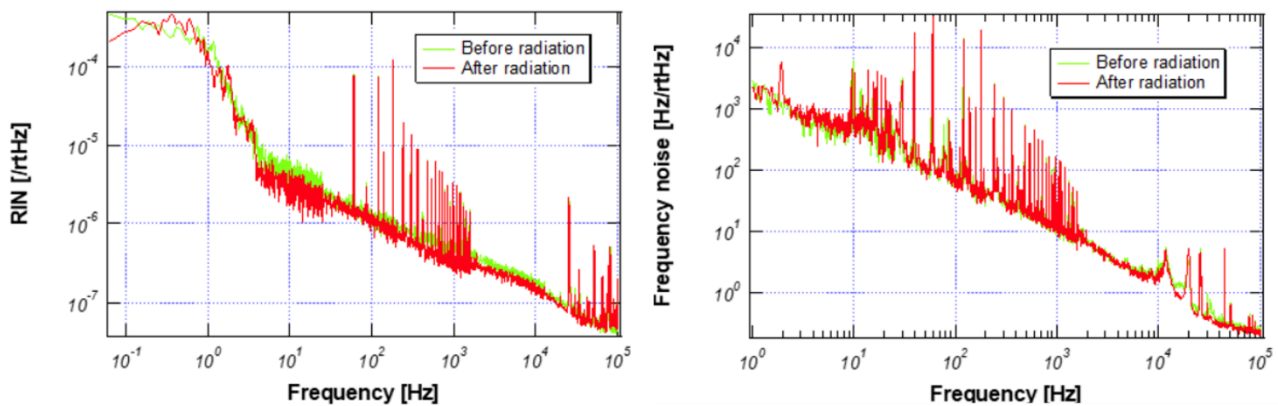


Figure 14 - Radiation test results of the MO EM model. RIN (left) and frequency noise (right) were tested before and after exposure.

5. CONCLUSION

Avo has completed the design of the LISA Laser System Main Oscillator and manufactured EM units that meet all performance and qualification requirements for the mission. As of August of 2026, Avo has begun manufacturing 12 Engineering Test Units, which will undergo further performance and environmental testing, as well as full-system lifetesting. Once testing is complete, the Qualifying Model and Flight Model builds are scheduled to begin in Q1 of 2027.

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REFERENCES

- [1] Danzmann, K., et al., “Laser Interferometer Space Antenna,” <https://arxiv.org/abs/1702.00786> (2017)
- [2] B.P. Abbott et al. (LIGO–Virgo–KAGRA Collaboration), Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA, Living Rev. Rel. 23 (2020) 1, 3.
- [3] Yu, A.W. et al. “Overview of the NASA LISA laser system development,” Class. Quantum Grav. 43 (2026) 035016
- [4] Thomas J. Kane and Robert L. Byer, “Monolithic, unidirectional single-mode Nd:YAG ring laser,” Opt. Lett. 10, 65-67 (1985).
- [5] Thomas J. Kane, Kenji Numata, Anthony Yu, Julia Majors, David R. Demmer, “Piezo-tuned nonplanar ring oscillator with GHz range and 100 kHz bandwidth,” Proc. SPIE 11980, Solid State Lasers XXXI: Technology and Devices, 1198008 (4 March 2022).