Optical Communication Activities through the Laser-Enhanced Mission Communications Navigation and Operational Services (LEMNOS) Office

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ABSTRACT

The Laser-Enhanced Mission Communications Navigation and Operational Services (LEMNOS) office at Goddard Space Flight Center (GSFC) manages two NASA optical communication related projects, the Orion EM-2 Optical Communications Terminal (O2O) and the Integrated Laser Communications Relay Demonstration (LCRD) Low-Earth Orbit (LEO) User Modem and Amplifier Terminal (ILLUMA-T) projects. The main goal of LEMNOS project is to implement optical communications technologies on NASA missions starting with demonstrations of operational utility on Orion EM-2 and the International Space Station.

1 INTRODUCTION

The use of optical communication for space systems has been under development since the early 1970s. These efforts were aided by the huge investment during the early 2000s in the terrestrial optical fiber communications industry that helped develop the technologies and components used in optical communications. Compared to radio-frequency technology, optical communications promise significantly higher data rates (as much as a hundred times more) in smaller size, weight, and power (SWaP) packages.

In recent years, NASA has been developing optical communication technologies to support future communication needs for science and human exploration missions. This paper describes activities under the LEMNOS office at GSFC for the advancement optical communications. Under LEMNOS there are two optical communication related projects, O2O and ILLUMA-T. LEMNOS is part of the Exploration and Space Communications (ESC) Projects Division at NASA's GSFC who is responsible for a significant part of NASA's communications. Both projects are collaborations between GSFC and the Massachusetts Institute of Technology – Lincoln Laboratory (MIT-LL) as well as a number of contractors. This paper provides information of the critical features of the two communication systems and offer an update on the development state of the two projects.

2 OPTICAL COMMUNICATIONS ACTIVITIES

While the potential benefits of optical communications for space applications have been recognized for many years, it is only recently that the engineering challenges associated with implementing such links have been overcome.

Lunar Laser Communication Demonstration (LLCD).
The first successful NASA's optical communication was the LLCD mission that flew onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) in 2013-2014. LLCD demonstrated a 622 Mbps return from a 10-cm gimbaled optical telescope with a 0.5-W laser transmitter to an optical receive telescope equipped with photon-counting receiver located in White Sands, New Mexico [1]. LLCD also demonstrated a 20-Mbps ground-to-space link based on a 40-W, 15-cm telescope transmitter and the 10-cm gimbaled telescope on the LADEE spacecraft as well as a ~1-cm spacecraft-to-ground range measurement capability utilizing the duplex wideband optical communication links.

Relay Optical Communications Systems
Besides the capability of direct-to-Earth communications, optical communications links may also offer many advantages in relay scenarios.

The European Space Agency (ESA) demonstrated optical communications between a spacecraft in LEO and a GEO relay in 2015 and today provides an operational 1.8-Gbps optical link capability with its European Data Relay Service (EDRS) [2]. NASA is currently working to demonstrate an advanced optical relay system known as the Laser Communication Relay Demonstration (LCRD) [3] in preparation for the next generation relay system. LCRD comprises a space segment with two optical space terminals coupled to a 2.8-Gbps differential-phase-shift-keyed modem, on GEO orbit and a ground segment with two optical ground terminals located in California and Hawaii. LCRD will be launched in 2019 onboard the Space Test Program Satellite 6 (STPSat-6).

3 LEMNOS ACTIVITIES

Orion EM2 Optical Communications Terminal

O2O is a NASA project sponsored by NASA's Human Exploration and Operations (HEO) Mission Directorate that will provide optical communications capability to the Orion Multi-Purpose Crew Vehicle (MPCV) series of spacecraft, starting with the demonstration of operational utility on Exploration Mission-2 (EM-2). It will be the first time a human exploration mission will rely on optical communications for its high-bandwidth link.

EM2 is a ~7-14 day mission that will transport humans to lunar vicinity for the first time since the Apollo missions. The primary communications link for the Orion vehicle is an S-band link that operates at rates of up to a few Mbps. The optical communications capability being developed for EM-2 will demonstrate direct-to-Earth return rates of up to 80-250 Mbps and forward rates up to 20 Mbps. The link architecture is very similar to the LLCD design.

This optical module will be coupled to a 1-W 1550-nm pulse-position modulation (PPM) modem to provide the downlink to Earth. A small ground terminal coupled to photon-counting detectors will be sufficient to receive the downlink signal at the planned data rates. The link will be used for high-rate file transfers to and from the Orion vehicle, video streaming and other applications over the course of the EM-2 mission.

Table 3.1 displays the level 1 requirements for the O2O mission, while Figure 1 depicts the implementation of the payload onboard Orion.

Table 3-1: O2O L1 Requirements

1.0	Develop an Optical Comm System to plan and demonstrate an operational optical comm link for Orion EM-2
2.0	Maintain a development path to a fully operational Optical Comm System
3.0	Flow data from Orion through the Optical Comm Fight Terminal to the Optical Comm Ground Terminal
4.0	Flow data from Optical Comm Ground Terminal to Optical Comm Fight Terminal and forward to Orion
5.0	Distribute data to/from Orion MOCC real time or store and distribute later
6.0	Flight terminal conforms to the Orion accommodations, mission objectives, and environments
7.0	Ground terminal and data system developed with operational interfaces

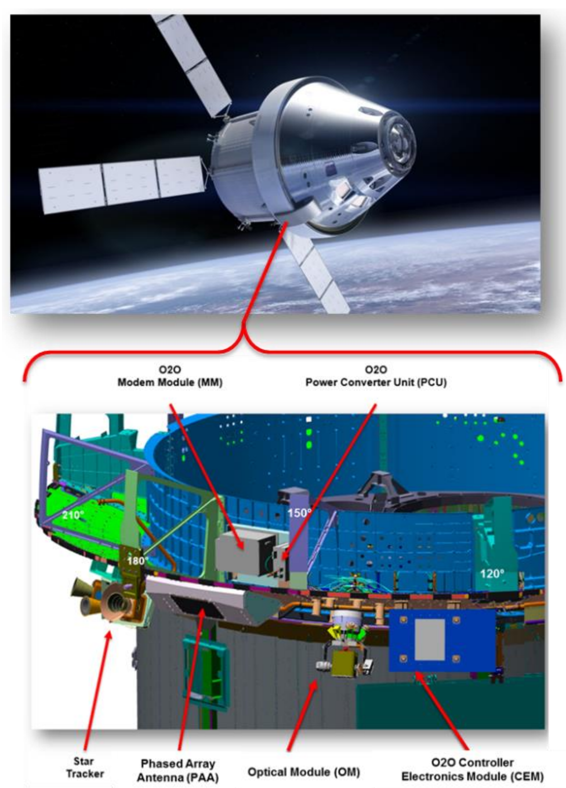


Figure 1: O2O system onboard the Orion spacecraft

Integrated Laser Communications Relay Demonstration (LCRD) Low-Earth Orbit (LEO) User Modem and Amplifier Terminal (ILLUMA-T)

ILLUMA-T is another NASA mission sponsored by the Space Communications and Navigation (SCaN) Program Office. The ILLUMA-T project will develop an optical communications user terminal to demonstrate high bandwidth data transfer between LEO and the ground through the LCRD relay on GEO orbit. ILLUMA-T is destined for the International Space Station (ISS) as an external payload attached to the Japanese Experiment Module - Exposed Facility (JEM-EF). The optical communication system will demonstrate relay communications between the ISS and LCRD relay, with return rates up to 1.244 Gbps and forward of at least 51 Mbps. ILLUMA-T will be the first demonstration of a LEO user of the LCRD system, pointing and tracking from a moving spacecraft at LEO to GEO satellite and vice versa, end-to-end operational utility of optical communications, and 51 Mbps forward link to ISS from ground.

Table 3.2 displays the level 1 requirements for the ILLUMA-T mission, while Figure 2 depicts the implementation of the payload onboard the ISS.

Table 3.2: ILLUMA-T L1 Requirements

1.1	The ILLUMA-T project shall demonstrate a duplex optical communications link from the ILLUMA-T terminal located on the ISS to a ground station via the LCRD satellite
1.2	The ILLUMA-T user terminal shall operate up to 1.244 Gbit/s on the return link (ISS to Ground) and up to 51 Mbps on the forward link (Ground to ISS)
1.3	The ILLUMA-T protoflight terminal shall be developed using an approach that includes participation of commercial companies and enables the transfer of optical communications technology to industry
1.4	The ILLUMA-T terminal orientation shall support line of sight to a ground station
1.5	The ILLUMA-T terminal shall support a bi-directional data connection of at least 1.0 Gbit/s (i.e. 100/1000 Mbps Ethernet connection)

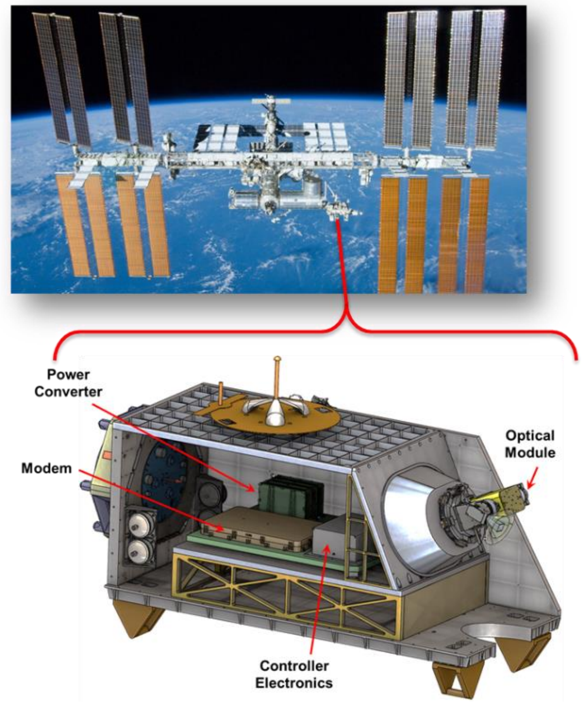
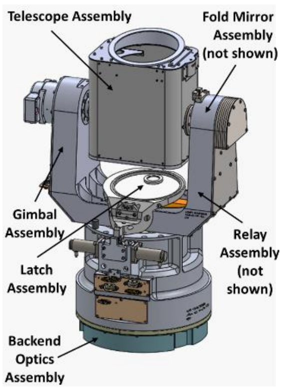
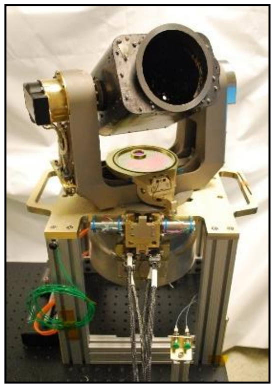


Figure 2: ILLUMA-T system onboard the ISS

4 TERMINAL TECHNOLOGY: Modular, Agile, Scalable Optical Terminal (MAScOT)

In an effort to support the varying needs of future missions, NASA together with MIT-LL have evolved the optical terminal technology that was developed for previous missions, like LLCD and LCRD. Recent development efforts have focused on evolving optical module design to make it more capable and reduce recurring costs associated with meeting various mission requirements. Both O2O and ILLUMA-T are using a common optical terminal based on a new design developed at MIT-LL for use in a wide variety of laser link scenarios, the Modular, Agile, Scalable Optical Terminal (MAScOT), see Fig. 3 [4]. MAScOT was first developed to provide a terminal for spacecraft in LEO where wide field of regard and fast slew rates are required. Key features of the MAScOT architecture is its modularity and scalability. The ILLUMA-T and O2O programs will demonstrate the viability of the MAScOT design for space missions, maturing it for operational use on future space missions. While current efforts are developing ~10-cm user terminals, larger apertures based on the same terminal design are also envisioned for future applications.





(a) *(b)*

Figure 3: MAScOT Optical Terminal (a) as-built CAD, and (b) Photograph of engineering unit, 10-cm MAScOT developed for use on Orion and the International Space Station

MAScOT has greater than hemispherical field-of-regard with pointing and tracking capabilities that can support fast-moving platforms in low-Earth orbit as is the case of the ISS. The 10-cm aperture is coupled to the back-end optics assembly via a Coudé path. The MAScOT terminal is coupled to a modem via optical fibers which connect to the back-end optics assembly. The MAScOT architecture is modular in that its subassemblies—the telescope, latch and gimbal, and back-end optics—may be developed independently by different groups so long as they adhere to specifications at the subassembly interfaces. The architecture is scalable in that various sizes of telescope may be accommodated without significant changes to the other subassemblies. For these reasons, it is believed that this terminal design will find many applications in cis-Lunar space and beyond.

5 CONCLUSION

The LEMNOS project comprises of two optical communication projects, O2O and ILLUMA-T. These projects will demonstrate operational utility of optical communications for human exploration and will provide high-data-rate for both space-to-space and space-to-ground links. These activities will further advance the application of optical communications for critical missions and pave the way for future use of the developed technologies.

Both projects employ a common modular optical terminal architecture that can be scaled to different sizes for use in a variety of missions. Furthermore the LEMNOS projects followed a seeded industry partnerships approach to develop the needed needed subassemblies in an effort to control cost and take advantage of industrial knowhow.

References

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