

Operational results of JAXA's optical data relay system LUCAS as of Oct. 2026

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ABSTRACT

The Laser Utilizing Communication System (LUCAS), launched by the Japan Aerospace Exploration Agency (JAXA) in November 2020, successfully established an optical inter-satellite link with its first user satellite, Advanced Land Observing Satellite-4 (ALOS-4, “Daichi-4”), in September 2024, shortly after the satellite’s launch in that year. Since then, LUCAS has continuously and successfully supported the transmission of observation data from ALOS-4. In addition, optical link experiments are being conducted with optical ground stations, whose future deployment is expected to further expand the utilization of optical communications. Notably, bidirectional optical links have been successfully demonstrated with a portable small-scale optical ground station developed by Kawasaki Heavy Industries, Ltd. This presentation reports on the operational status and mission achievements of LUCAS as of October 2026.

Keywords: LUCAS, Optical data relay satellite, Optical Ground Station

1. INTRODUCTION

In recent years, the volume of data generated by Earth observation satellites has continued to increase due to advances in sensor capabilities, including higher spatial resolution and wider observation swaths. Furthermore, the applications of Earth observation satellites have expanded beyond environmental monitoring to include disaster response and other time-critical missions. Consequently, there is a growing demand for reducing the turnaround time, defined as the interval between the issuance of an observation request and the delivery of the corresponding observation data to the end user.

To address these challenges, the Japan Aerospace Exploration Agency (JAXA) initiated the development of the Laser Utilizing Communication System (LUCAS) in FY2015. A data relay satellite is positioned in a high-altitude orbit, such as geostationary orbit, providing continuous visibility over a wide coverage area and serving as a communication relay between low Earth orbit (LEO) satellites, including Earth observation satellites, and ground stations. Under conventional direct-to-ground communications, contact opportunities between a LEO satellite and a mid-latitude ground station are typically limited to two or three passes per day, each lasting approximately 10 to 15 minutes. By employing a data relay satellite, however, communication opportunities can be increased to approximately 14 passes per day, each exceeding 40 minutes, thereby significantly improving both data delivery timeliness and communication capacity.

LUCAS is a satellite communication system that combines optical inter-satellite communication technology with the data relay satellite architecture, enabling high-capacity and low-latency data transmission from Earth observation satellites to ground users.

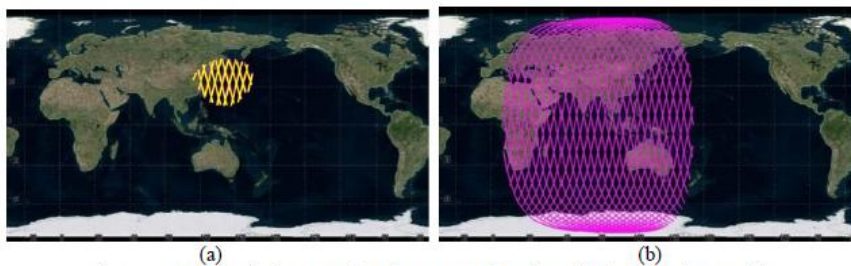


Figure 1. Communication area (a)using a ground station, (b) via data relay satellite

2. OUTLINE OF LUCAS

Specifications

Figure 2 shows the system configuration of LUCAS, while its main specifications are listed in Table 1.

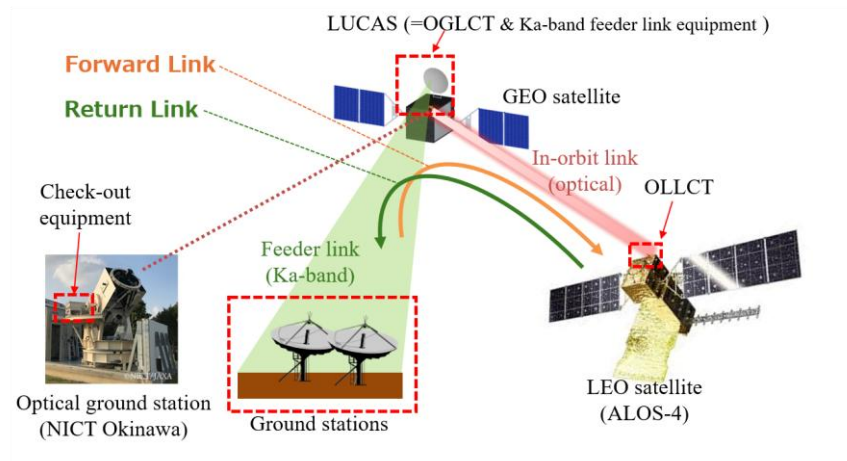


Figure 2. System configuration of LUCAS

Table 1 Specifications of LUCAS

	Launch: Nov. 2020
	Mission period: 10 years
	Inter-at. Communication: • Wavelength: 1.5 μ m • Communication speed: Return link: 1.8Gbps Forward link: 50Mbps

The communication path from a ground station to a user satellite through the terminal onboard the geostationary relay satellite is defined as the forward link, while the communication path from a user satellite to a ground station through the same relay satellite is defined as the return link. LUCAS is equipped with the Optical GEO Laser Communication Terminal (OGLCT), whereas the user satellite ALOS-4 is equipped with the Optical LEO Laser Communication Terminal (OLLCT). The inter-satellite segment employs high-capacity optical communications, while the feeder link to the ground station utilizes a Ka-band RF communication system, selected for its robustness against atmospheric and weather-induced impairments.

Data Architecture

The transmission rates of LUCAS were determined based on the data-generation characteristics of Earth observation satellites targeted by JAXA and the anticipated operational communication requirements. The data rates were specified as 50 Mbps for the forward link and 1.8 Gbps for the return link. Since additional overhead, including forward error correction (FEC) coding and bit synchronization sequences, is incorporated into the transmission frame, the corresponding symbol rates are approximately 60 Mbaud for the forward link and 2.5 Gbaud for the return link.

Furthermore, burst errors caused by tracking inaccuracies, as described later, were anticipated during system design. To mitigate their impact, an interleaving process was introduced to disperse burst errors over the time domain, thereby converting them into random-like errors that can be effectively corrected by the FEC scheme.

Laser Communication Terminal Design

The aperture sizes of the Laser communication terminals were determined by considering factors such as the sensitivity of available optical receivers, the output power of high-power optical amplifiers, and the achievable wavefront quality and manufacturing accuracy of the optical system. As a result, the aperture diameters were set to approximately 140 mm for the GEO terminal and 90 mm for the LEO terminal. The GEO-side terminal, which is required to receive high-speed data at 1.8 Gbps, necessitated a relatively large aperture to achieve sufficient receiver sensitivity and link margin. In contrast, the LEO-side terminal receives data at the lower rate of 50 Mbps and was subject to stringent mass and size constraints. Consequently, its aperture was minimized as much as possible while maintaining the required communication performance. For these reasons, different aperture sizes were adopted for the GEO and LEO optical communication terminals.

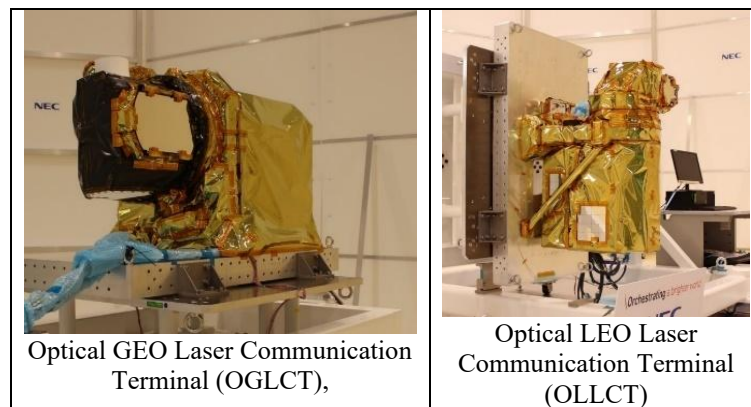


Figure 3. Laser Communication Terminals

Overview of Pointing, Acquisition, and Tracking (PAT) Design

Based on the terminal design, the tracking accuracy required to maintain a communication link in LUCAS was determined to be approximately $10 \mu\text{rad}$. During communication operations, the counterpart satellite must be continuously maintained within this pointing accuracy. However, achieving tracking accuracy on the order of $10 \mu\text{rad}$ through open-loop pointing alone is not practical, as numerous error sources contribute to overall pointing uncertainty. These include alignment errors between the optical terminal and the satellite structure, thermally induced distortions, spacecraft attitude determination and control errors, and orbit determination errors.

To address these challenges, the Pointing, Acquisition and Tracking (PAT) function was introduced. PAT consists of two fundamental processes: acquisition, in which the counterpart satellite is detected and brought within the communication beam, and tracking, in which the counterpart satellite is continuously maintained within the beam during communication. Prior to communication operations, an acquisition sequence is executed to establish the PAT link by progressively reducing the pointing uncertainty between the two satellites. The sequence is designed to narrow the uncertainty region step by step until mutual optical acquisition is achieved. The overall acquisition sequence is illustrated in Figure 4.

After transitioning to the fine-tracking mode, both satellites continuously maintain mutual tracking of each other's optical beams throughout the communication session. In addition, the PAT system is designed to compensate for light aberration throughout the entire acquisition and tracking process. Light aberration is the apparent displacement of the incoming optical signal from the actual position of the counterpart satellite due to the relative velocity between the two satellites. Such compensation is essential for maintaining accurate beam pointing and stable optical link performance.

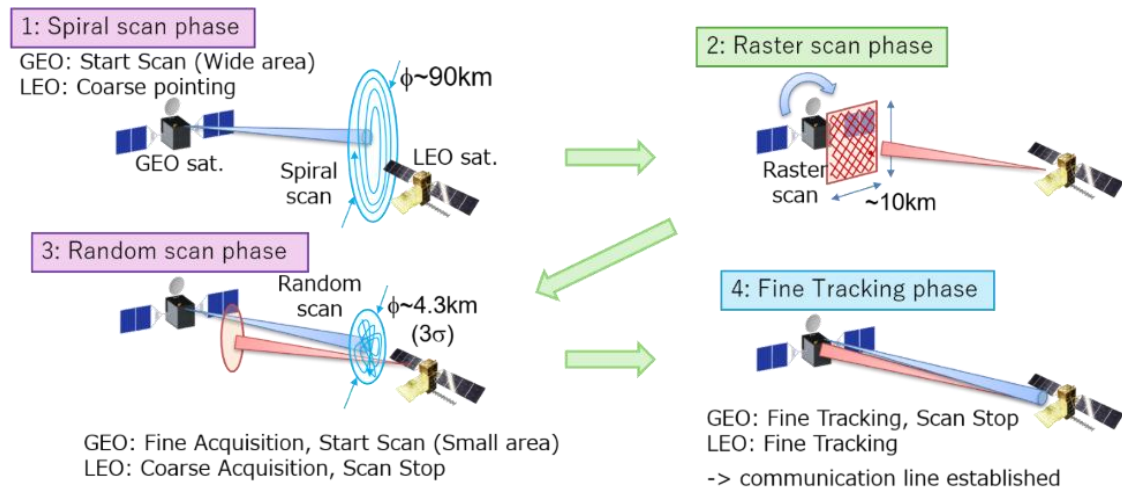


Figure 4. PAT sequence

3. OPERATIONAL PERFORMANCE OF LUCAS

The allocation of operational availability requirements, corresponding design considerations, and on-orbit operational performance of LUCAS are presented below. The operational performance statistics were compiled using data collected between 11 August 2025 and 2 August 2026, after completion of all on-orbit parameter tuning activities, representing a total accumulated communication time of 59,340 s. The initial acquisition success rate did not reach the value anticipated during system design because several phenomena not considered in the original design became evident during on-orbit operations, including unintended behavior of the Earth background-light processing algorithm. Nevertheless, the overall system performance satisfied the target operational availability requirement, and the mission successfully achieved its operational performance objectives as a whole.

Table 2 Operational Performance of LUCAS

Item	Allocation	Design results	Operational Performance	Remarks
Burst error impact	0.999	>0.9999	0.999999437	Occurred a total of 3 times during the period, for only 33.4 ms
Tracking loss impact	0.999	>0.9999	1	Did not occur during this phase
Initial PAT success rate	0.99	>0.99	0.9771	Did not occur during this phase
Sun glint impact	0.983	>0.984	-	Excluded in the operational plan for ALOS-4
The impact of rainfall on feeder link	0.999	>0.99	1	There were no cases in which the feeder link became unavailable due to rain during the optical operations period.
Ground system availability	0.99	>0.999	1	There were no cases in which the optical ground system became unavailable during the optical operations period.
Margin	0.99	-	-	
Operational achievement rate	0.95	>0.97	0.977	

4. OPTICAL LINK DEMONSTRATION BETWEEN LUCAS AND OPTICAL GROUND STATIONS

Optical Ground Stations (OGSs) are expected to play a key role in future communications infrastructure as gateways between Non-Terrestrial Networks (NTNs), including satellite communication systems, and conventional Terrestrial Networks (TNs). Recognizing their importance for the future development of NTN architectures, JAXA initiated efforts to establish optical link technologies between LUCAS and OGSs.

PAT Operational Procedure for Optical Links with OGSs

The nominal Pointing, Acquisition and Tracking (PAT) sequence of LUCAS, developed for inter-satellite optical communications, assumes that the LEO-side user terminal is equipped with a transmit-beam scanning capability. Under this assumption, the acquisition process begins with a wide-area scan, typically a spiral scan covering a region larger than the open-loop pointing uncertainty, and gradually narrows the search area until an optical link is established with the counterpart satellite.

However, many OGSs currently under development are not equipped with beam-scanning capabilities, making the nominal inter-satellite acquisition procedure directly inapplicable. To address this limitation, an alternative operational procedure was devised in which the raster-scan phase shown in Figure 4 is omitted. In this approach, the OGS only needs to transmit a continuous optical beacon toward the satellite once it detects the random-scan beam transmitted by LUCAS, thereby enabling establishment of the optical link.

The primary challenge of this approach is that the coverage area of the random scan is smaller than the overall open-loop pointing uncertainty region. Consequently, there is no guarantee that the OGS will be illuminated solely through random scanning. To overcome this issue, an operational procedure was developed in which the pointing direction of LUCAS is manually adjusted through a series of predefined offsets until an optical link with the OGS is successfully established. The corresponding operational flow is illustrated in Figure 5.

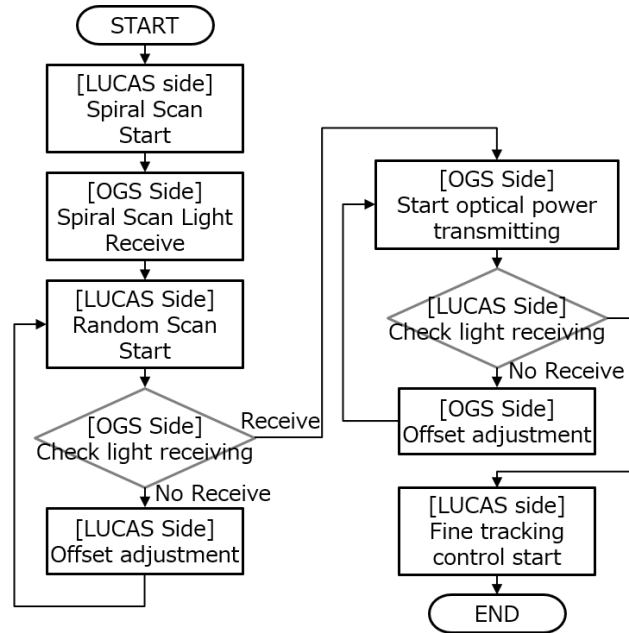


Figure 5. PAT Operational Procedure for Optical Links with OGSs

To define the pointing offsets applied during the random-scan operation, an offset map was established as shown in Figure 6. The offset locations were selected such that the random-scan coverage areas collectively provide continuous

spatial coverage without gaps. In the figure, each circle represents the area covered by a single random-scan operation, while the number within each circle indicates the corresponding offset-direction identifier.

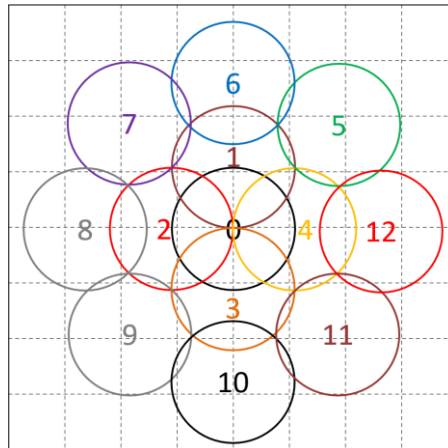


Figure 6. Offset-Direction Map for Random-Scan Operations

Demonstration Results

Through a collaborative research program with Kawasaki Heavy Industries, Ltd. (KHI), which has been independently developing a compact and portable Optical Ground Station (OGS), a bidirectional optical link was successfully established using the operational procedure described above. Telemetry data obtained during the demonstration are shown in Figure 7. As demonstrated by the performance of LUCAS, the random-scan beam could be directed toward the OGS with a high probability using offset directions 0 or 1 in the offset map.

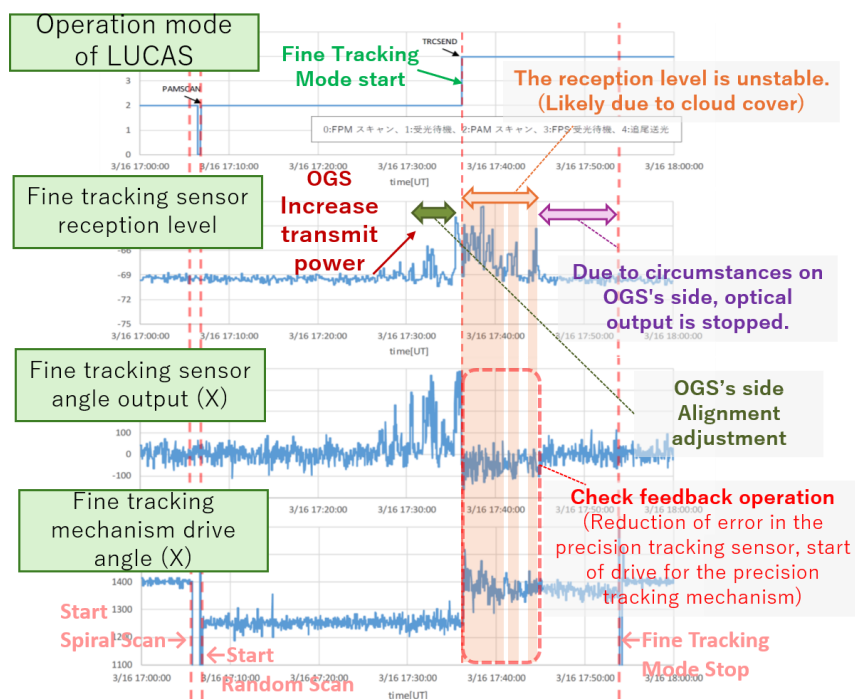


Figure 7. PAT Telemetry Data During Optical-Link Acquisition with the OGS

Both the acquisition-and-tracking sensor output and the fine-tracking mechanism drive angle consist of measurements in the X- and Y-axes. For brevity, only the representative X-axis data are presented here. Although the received optical signal level fluctuated during the experiment due to atmospheric and weather-related effects, the telemetry data indicate that the fine-tracking mechanism became active immediately after LUCAS entered the fine-tracking mode. Simultaneously, the tracking error measured by the fine-tracking sensor decreased, demonstrating proper operation of the closed-loop tracking system. Based on these observations, it was confirmed that the PAT feedback control function operated as intended. Accordingly, the bidirectional optical-link demonstration was assessed as partially successful, despite the impact of environmental conditions on link stability.

5. FUTURE PLANS

Due to scheduling constraints, the present demonstration did not allow for extended tracking operations under favorable atmospheric conditions. To further evaluate system performance, a follow-on experiment is planned within 2026 with the objective of acquiring additional operational data under improved weather conditions. Furthermore, similar experiments are planned with overseas Optical Ground Stations (OGSs) to demonstrate bidirectional optical links in a broader operational environment.

Building upon the outcomes of these activities, we aim to contribute to the realization of future space communication infrastructures in which terrestrial networks (TNs) and non-terrestrial networks (NTNs) are seamlessly integrated.

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