SAMPLE

Cosmic Explorers: Communication in Space

How Spacecraft Talk to Earth

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

Laser communication in space is the use of free-space optical communication in outer space. Communication may be fully in space (an inter-satellite laser link) or in a ground-to-satellite or satellite-to-ground application. The main advantage of using laser communications over radio waves is increased bandwidth, enabling the transfer of more data in less time. In outer space, the communication range of free-space optical communication is currently of the order of hundreds of thousands of kilometers.

Laser-based optical communication has been demonstrated between the Earth and Moon and it has the potential to bridge interplanetary distances of millions of kilometers, using optical telescopes as beam expanders. On 20 January 1968, the television camera of the Surveyor 7 lunar lander successfully detected two argon lasers from Kitt Peak National Observatory in Arizona and Table Mountain Observatory in Wrightwood, California.

In 1992, the Galileo probe proved successful one-way detection of laser light from Earth as two ground-based lasers were seen from 6,000,000 km (3,700,000 mi) by the out-bound probe. The first successful laser-communication link from space was carried out by Japan in 1995 between the NASDA's ETS-VI GEO satellite and the 1.5 m (4 ft 11 in) National Institute of Information and Communications Technology (NICT)'s optical ground station in Tokyo achieving 1 Mbit/s.

In November 2001, the world's first laser intersatellite link was achieved in space by the European Space Agency (ESA) satellite Artemis, providing an optical data transmission link with the CNES Earth observation satellite SPOT 4. The link moved 50 Mbps over the roughly 40,000 km (25,000 mi) gap separating low-Earth orbit from the geostationary belt. Since 2005, ARTEMIS has been relaying two-way optical signals from Kirari, the Japanese Optical Inter-orbit Communications Engineering Test Satellite.

In May 2005, a two-way distance record for communication was set by the Mercury laser altimeter instrument aboard the MESSENGER spacecraft. This diode-pumped infrared neodymium laser, designed as a laser altimeter for a Mercury orbit mission, was able to communicate across a distance of 24,000,000 km (15,000,000 mi), as the craft neared Earth on a fly-by. In 2006, Japan carried out the first LEO-to-ground laser-communication downlink from JAXA's OICETS LEO satellite and NICT's optical ground station.

In 2008, the ESA used laser communication technology designed to transmit 1.8 Gbit/s across 40,000 km (25,000 mi), the distance of a LEO-GEO link. Such a terminal was successfully tested during an in-orbit verification using the

German radar satellite TerraSAR-X and the American Near Field Infrared Experiment (NFire) satellite. The two Laser Communication Terminals (LCT) used during these tests were built by the German company Tesat-Spacecom, in cooperation with the German Aerospace Center (DLR).

In January 2013, NASA used lasers to beam an image of the Mona Lisa to the Lunar Reconnaissance Orbiter (LRO) roughly 390,000 km (240,000 mi) away at night from the Next Generation Satellite Laser Ranging (NGSLR) Station at NASA's Earth-based Goddard Space Flight Center. To compensate for atmospheric interference, an error correction code algorithm similar to that used in CDs was implemented.

In September 2013, a laser communication system was one of four science instruments launched with the NASA LADEE (Lunar Atmosphere and Dust Environment Explorer) mission. After a month-long transit to the Moon and a 40-day spacecraft checkout, daytime laser communications experiments were performed over three months during late 2013 and early 2014.

Initial data returned from the Lunar Laser Communication Demonstration (LLCD) equipment on LADEE set a space communication bandwidth record in October 2013 when early tests using a pulsed laser beam to transmit data over the 385,000 km (239,000 mi) between the Moon and Earth passed data at a "record-breaking download rate of 622 megabits per second (Mbps)", and also demonstrated an error-free data upload rate of 20 Mbit/s from an Earth ground station to LADEE in lunar orbit.

The LLCD is NASA's first attempt at two-way space communication using an optical laser instead of radio waves, and is expected to lead to operational laser systems on NASA satellites in future years. In November 2013, laser communication from a jet platform Tornado was successfully demonstrated for the first time.

A laser terminal of the German company Mynaric (formerly ViaLight Communications) was used to transmit data at a rate of 1 Gbit/s over a distance of 60 km and at a flight speed of 800 km/h in daylight. Additional challenges in this scenario were the fast flight maneuvers, strong vibrations, and the effects of atmospheric turbulence. The demonstration was financed by EADS Cassidian Germany and performed in cooperation with the German

Aerospace Center DLR.

Chapter 01: The Discovery of Communication in Space

An ESA terminal flown in 2008 pushed 1.8 Gbit/s across the long climb between low-Earth orbit and geostationary altitude, a span near 40,000 km

(25,000 mi). In November 2014, the first ever use of gigabit laser-based communication as part of the European Data Relay System (EDRS) was carried out. Further system and operational service demonstrations were carried out in 2014.

Data from the EU Sentinel-1A satellite in LEO was transmitted via an optical link to the ESA-Inmarsat Alphasat in GEO and then relayed to a ground station using a conventional Ka-band downlink. The new system can offer speeds up to 7.2 Gbit/s. The Laser terminal on Alphasat is called TDP-1 and is still regularly used for tests. The first EDRS terminal (EDRS-A) for productive use has been launched as a payload on the Eutelsat EB9B spacecraft and became active in December 2016.

It routinely downloads high-volume data from the Sentinel 1A/B and Sentinel 2A/B spacecraft to ground. So far (April 2019) more than 20000 links (11 PBit) have been performed. As of May 2023, EDRS has over one million minutes of communications with more than 50,000 successful inter-satellite links. In December 2014, NASA's Optical Payload for Lasercomm Science (OPALS) announced a breakthrough in space-to-ground laser communication, downloading at a speed of 400 megabits per second.

The system is also able to re-acquire tracking after the signal is lost due to cloud cover. The OPALS experiment was launched on 18 April 2014 to the International Space Station (ISS) to further test the potential for using a laser to transmit data to Earth from space. The first LEO-to-ground lasercom demonstration using a Japanese microsatellite (SOCRATES) was carried out by NICT in 2014, and the first quantum-limited experiments from space were done by using the same satellite in 2016.

In February 2016, Google X announced to have achieved a stable laser communication connection between two stratospheric balloons over a distance of 100 km (62 mi) as part of Project Loon. The connection was stable over many hours and during day and nighttime and reached a data rate of 155 Mbit/s. In June 2018, Facebook's Connectivity Lab (related to Facebook Aquila) was reported to have achieved a bidirectional 10 Gbit/s air-to-ground connection in collaboration with Mynaric.

The tests were carried out from a conventional Cessna aircraft in 9 km (5.6 mi)

distance to the optical ground station. While the test scenario had worse platform vibrations, atmospheric turbulence and angular velocity profiles than a stratospheric target platform the uplink worked flawlessly and achieved 100% throughput at all times. The downlink throughput occasionally dropped to about 96% due to a non-ideal software parameter which was said to be easily fixed.

In June 2021, the US Space Development Agency launched two 12U CubeSats to Sun-synchronous orbit to demonstrate laser communication links between the satellites and a remotely controlled MQ-9 Reaper. On December 7, 2021, NASA's Laser Communications Relay Demonstration (LCRD) launched as part of USAF STP-3, to communicate between geosynchronous orbit and the Earth's surface. In May 2022, TeraByte InfraRed Delivery (TBIRD) was launched (on PTD-3) and tested 100 Gbit/s comms from 300 mile orbit to California.

Laser communications in deep space will be tested on the Psyche mission to the main-belt asteroid 16 Psyche, launched in 2023. The system is called Deep Space Optical Communications (DSOC), and is expected to increase spacecraft communications performance and efficiency by 10 to 100 times over conventional means. In April 2024, the test was successfully completed with the Psyche spacecraft at a distance of 140 million miles.

In April 2026, the crewed Artemis II mission successfully used a laser communication system known as the Orion Artemis II Optical Communications System (O2O).

Japan's National Institute of Information and Communications Technology (NICT) will demonstrate in 2022 the fastest bidirectional lasercom link between the geosynchronous orbit and the ground at 10 Gbit/s by using the HICALI (High-speed Communication with Advanced Laser Instrument) lasercom terminal on board the ETS-9 (Engineering Test Satellite IX) satellite, as well as the first intersatellite link at the same high speed between a CubeSat in LEO and HICALI in GEO one year later.

As of May 2024, a Full Trasceiver type terminal compatible for CubeSat has been designed and in development. CubeSOTA is expected to launch during the Japanese fiscal year 2025 with the terminal for "demonstrating various scenarios, including LEO-ground, LEO-HAPS, and LEO-LEO." CubeSOTA "will be the first in-orbit validation of the terminals."

LunaNet is a NASA and ESA project and proposed data network aiming to provide a so-called Lunar Internet for cis-lunar spacecraft and installations.

The radio era of spaceflight began with a beeping sphere. In late 1957, the first satellite broadcast a steady pulse on shortwave frequencies that any

listener with a modest receiver could hear, and around the world people pointed improvised antennas at the sky to catch it. That little transmitter did more than prove a launch; it created the first global audience for a machine in orbit and, in effect, recruited thousands of amateurs as an unpaid ground network. Within two years, a Soviet probe had photographed the Moon's hidden face, developed the film onboard, scanned it line by line, and transmitted the result to Earth: the first fax from another world, and the first demonstration that a spacecraft could carry its own darkroom and send pictures home on a schedule set by physics rather than patience.

The early deep space records came fast. In 1960, a small solar observing probe established two way communication across tens of millions of kilometers, an astonishing reach for hardware that fit in a satellite the size of a beach ball. Two years later, the first successful probe to Venus, crossing a distance no craft had ever reported from, transmitted with a radio that radiated only a few watts, and the signals were gathered by antennas that would look modest today. Mars followed in 1965, when a flyby craft returned the first close up images of another planet: a couple of dozen pictures, each taking minutes to send and arriving line by line onto a screen as engineers crowded around. The lesson of the first decade was that distance was survivable, but only barely, and every mission after built its plans around the arithmetic of the downlink.

Storage was the other discovery of that era. Early probes carried tape recorders that could hold a flyby's observations when no station was in view and play them back later, which made a mission far more efficient than one chained to live transmission. The recorder aboard the first successful Mars flyby let the craft bank its images during the encounter and trickle them home afterward, and when a radiation hit corrupted part of the tape, engineers reconstructed the missing lines by hand from timing data. Store and forward, now a foundational idea of space networking, began as a mechanical solution to the awkwardness of planetary geometry: sometimes the world that wants the data is simply not facing the right way.

The relay idea, so central to modern planning, is older than many readers guess. The two Viking missions of the 1970s, each an orbiter paired with a lander, already flew the pattern: the landers, squat machines with modest antennas, handed their data to the orbiters sweeping overhead, and the orbiters carried the harvest back to Earth. The Apollo program made its own contribution to the field's toolkit with a unified radio system that carried voice, telemetry, ranging, and television on a single carrier, a design decision that simplified hardware on both ends and set patterns that deep space missions still echo. The 1970s also sent probes to the cloud tops of Venus that returned

the first pictures from the surface of another planet, transmitted from machines sitting under an atmosphere hot enough to melt lead, a reminder that the communication engineer's environment includes the far end's weather as much as the vacuum in between.

Understanding the system, then, means holding two pictures at once. One is the chain: a transmitter, a dish, a vacuum crossing, a receiver, a decoder, an archive. The other is the institution around the chain: the calendars, the agreements, the backups, and the people who keep the whole arrangement honest. A reader who grasps both understands why a mission can be delayed by a cloudy morning on one continent, why a station on the far side of the planet can rescue a spacecraft in the other hemisphere, and why the true textbook of the field is as much a collection of procedures as it is a set of physics equations, or would be, if this series permitted equations.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.