Cubesat Laser Communications Transceiver for Multi-Gbps Downlink

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ABSTRACT

Fibertek is developing a cubesat laser communications (lasercom) downlink terminal that supports direct optical data downlink from cubesats to modest optical ground stations with 30 to 50 cm diameter telescopes.

This paper describes the design, development, and lab testing of the optical transceiver portion of a compact cubesat space lasercom terminal. The design uses a relatively large aperture, low divergence, and accurate pointing approach to minimize the required laser power as well as the overall electrical power of the system. The optical transceiver has a shared transmit/receive optical path that uses a 1 um laser beacon to ensure high pointing accuracy, control the pointing stability, and ensure a strong optical signal-to-noise ratio (SNR) during link operation. The fundamental terminal optical design has been manufactured and tested providing high accuracy pointing and low jitter. The systems design is completed by adding a cubesat form-factor 1.5-um fiber-amplifier with 2 W optical power, high-data-rate optical transceiver card, and digital-modem/bus-interface card to lasercom terminal capable of supporting >5 Gbit/sec optical downlink.

INTRODUCTION

Fibertek is developing a cubesat lasercom system for use in earth and asteroid/comet science missions and as a satellite avionics communications system. This paper reports on progress made in the cubesat lasercom terminal development, its key design features, and the expected performance of the system.

Space-based laser communications demonstrations over the past several years have demonstrated that high-speed optical downlink from space is possible and that high bandwidth can be achieved.

Recent space missions demonstrating space lasercom performance include the following:

- NASA Lunar Laser Communications Demonstration (LLCD).[1]
- NASA has plans to demonstrate an Earth-based laser communications relay.[2]
- The European Space Agency (ESA) is building a lasercom space network.[3]
- NASA Jet Propulsion Laboratory (JPL) demonstrated an International Space Station (ISS)-to-Earth downlink (OPALS).[4]
- NASA JPL is developing the Deep Space Optical Communications (DSOC) system for the Psyche Discovery mission.[5]

These missions have demonstrated that laser communications is feasible and is emerging as an important capability to increase communication bandwidth and reduce size, weight, and power (SWaP) to augment radio frequency (RF) communications.

To make lasercom affordable and satellite friendly, there is considerable ongoing activity to develop the next-generation lasercom systems into a much smaller form-factor, including cubesats with much reduced SWaP compared to the current space programs.

Cubesat laser communications systems have been under development over the past 5 years including the following key activities:

- NASA JPL developed a compact laser communications optical terminal for deep space.[6,7,8]
- The Aerospace Corporation is on the threshold of demonstrating a cubesat lasercom downlink from low earth orbit (LEO) in 2017 (Figure 1).9 [Welle] The satellite will demonstrate ~ 200 Mbps communications from LEO.

Figure 1: NASA, Aerospace Corporation: Optical Communications and Sensor Demonstration Satellite[9,10]

SCIENCE AND AVIONICS NEED FOR LASERCOM

Laser communications is needed for NASA cubesat science missions. Studies by NASA JPL concluded that the SWaP benefits, particularly the electrical power benefits of laser communications, is compelling for beyond geosynchronous earth orbit (GEO) applications.[11]

The Keck Institute is conducting a workshop study entitled "Optical Communication on SmallSats: Enabling the Next Era in Space." The Institute will publish a report in 2017 detailing the enabling benefit and need for cubesat/smallsat laser communications to support NASA Earth and Exploration science missions.[12] In many cases, the data rate possible from available cubesat RF systems enables download of only a small fraction of the data. The small data stream can limit the science value of the mission and can impede mission operation planning and miss science opportunities because power and space requirements limit on-board computational and decision-making capability and the ability to reprogram in flight.

NASA science cubesat missions like MinXSS are being deployed beyond LEO, have captured science data, and have demonstrated that precision satellite pointing is possible.[13,14] Early studies by JPL identified cubesat laser communications as critical for exploration including planetary, asteroid, and science missions.

MISSION IMPLEMENTATIONS – LEO, GEO, INTERPLANETARY

The cubesat laser communications efforts being reported as applicable for earth and inter-planetary cubesats and smallsat missions are shown in Figure 2.

Applications include:

- Heliophysics science such as MinXSS with ranges up to ¼ to 1 astronomical unit (AU).
- Planetary science and small-body science including asteroid and comet missions.
- Earth data downlink and space crosslink networks.
- Support data rates needed for cameras with high-resolution imaging spectrometer and hyper-spectral imaging sensors for smallsats or cubesats.
- NASA's Space Communication and Navigation (SCaN) 2025 roadmap envisions such highly capable cubesats traversing the interplanetary highway within the asteroid belt to form an integrated network of communications relays.

RF communications technology is most commonly used for communication from spacecraft. However, for a given aperture an optical communications downlink can significantly increase the available downlink data rates, which are needed by the ever-growing data needs generated by such advanced payloads.

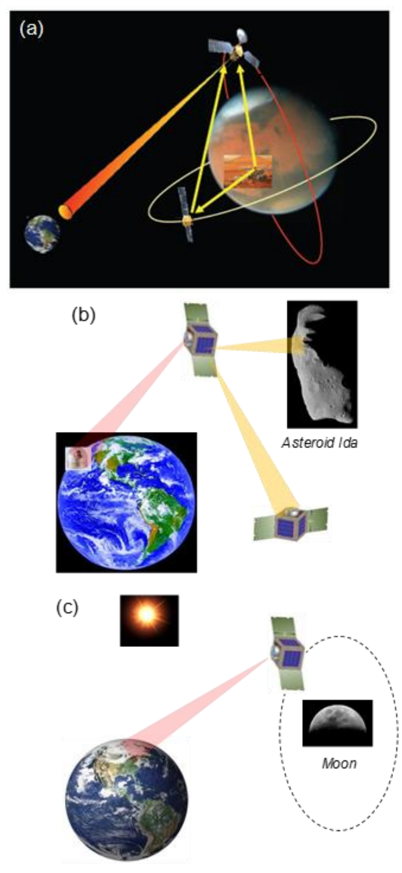
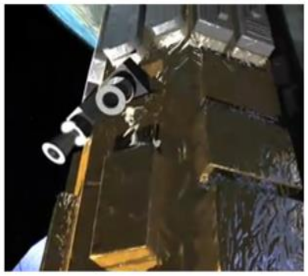
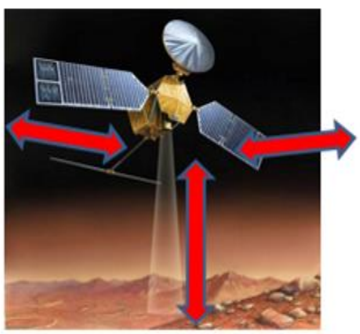


Figure 2: Potential Mission Scenarios for Deep-Space Cubesat Lasercom

Top: (a) Mars rover relay to Earth, (b) asteroid mission, (c) lunar optical communication. Bottom: Fibertek's strategy has been to develop compact lasercom terminals at Class A/B mission cost points to enable spacecraft to support multiple units for cross-links and downlink to support ring and mesh topologies. We leverage space-qualified gimbal mounts and Ka band coarse pointing technology.



Mount 1 or more units to sensor aggregation, planetary uplink, network cross ink



Multi-Function Orbiter Resources

DESIGN PROPERTIES

The overall design of a laser communications system is shown in Figure 3. It consists of an optical transceiver head and supporting lasers, modems, and radiation-tolerant instrument controller. The design incorporates a fast steering mirror (FSM) and 1 um beacon sensor to support precision pointing and point-ahead capability. If required, the architecture can also support a 1.5-um beacon and receiver detector, and has provisions to add full-duplex communications in the future.

Key design features include:

- Cubesat form factor for multi-Gb/sec links from LEO/medium Earth orbit (MEO).
- The power and size of the system can be customized based on receiver apertures, power budgets, and cost:
  - Low SWaP: ~ 2 kg and < 30 W for general Earth missions.
  - For interplanetary lasercom the power can be reduced to 10-14 W based on optimizing the link budget and pointing.
- Innovative monolithic design and fabrication of the optical assembly.
- Integrated beam point-ahead capability and beam-pointing stabilization.
- Reconfigurable and highly capable processing platform. Modem supports on/off keying, pulse position modulation (PPM), and in the future, differential phase shift keying (DPSK).
- Diffraction-limited shared transmitter/receiver (Tx/Rx) aperture telescope.
- Athermalized optical design of a fiber-coupled optical telescope for lasercom transmit/receive.
- Integrated active pointing stabilization.
- Satellite body-pointing or two-axis gimbals for coarse point/track.
- Modular design of optics and avionics and scalable to longer space links.
- Design can support position sensitive detector (PSD), quad detector, or focal plane array position sensors.
- System can be made cost-effectively for high-reliability Class A/b missions or low-cost missions.

The prototype optical transceiver has been designed, built, and tested with a closed-loop pointing control to 10 urad. The telescope assembly optical performance has been verified for transmit/receive optical parameters (e.g., wavefront and throughput). The unit has passed engineering vibration tests.

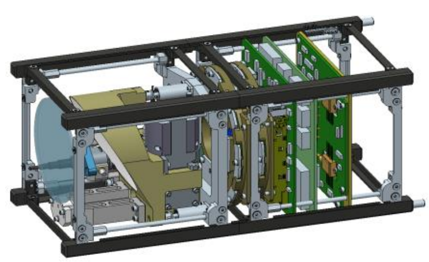


Figure 3: Cubesat Lasercom Terminal Including Optical Head, Laser Transmitter, Modem and Instrument Controller

VEHICLE AND COARSE POINTING OPTIONS

A high-performance lasercom link requires fine-pointing jitter stabilization down to the ~10 □rad level. To achieve this a two-level control scheme is used with the inner-loop rate control provided by the FSM. The outer-loop control, i.e., for coarse-tracking, is provided via recently developed high-precision star-trackers, which have demonstrated performance to <100 □rad (3□) pointing control at ~1 Hz rate. The lasercom terminal can be deployed for cube, small, and large satellites using the spacecraft or precision gimbal mounts for coarse pointing as shown in Figure 4. Precision cubesat body pointing sufficient to support laser communications is available for multiple new space cubesat suppliers.

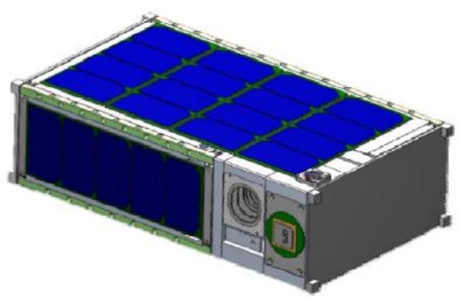


Figure 4: Concept of Operation of Lasercom Terminal in a 6U Cubesat Bus

Coarse pointing provided by the 6U satellite GNC system and fine-pointing provided inside the lasercom terminal. For small or large satellite applications, the terminal can be mounted on a precision space-qualified gimbal mount.

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