Progress in Design and Construction of the Optical Communications Laser Laboratory

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The deployment of advanced hyperspectral imaging and other Earth sensing instruments onboard Earth observing satellites is driving the demand for high-data-rate communications. Optical communications meet the required data rates with small, low-mass, and low-power communications packages. JPL, as NASA's lead center in optical communications, plans to construct a 1-m Optical Communications Telescope Laboratory (OCTL) at its Table Mountain Facility (TMF) located in the San Gabriel Mountains of Southern California at an altitude of 2.29 km. The design of the building has been completed, and the construction contractor has been selected. Groundbreaking is expected to start at the beginning of the 1999 TMF construction season. A request for proposal (RFP) has been issued for the procurement of the telescope system. Prior to releasing the RFP, we conducted a request for information with industry for the telescope system. Several vendors responded favorably and provided information on key elements of the proposed design. These inputs were considered in developing the final requirements in the RFP.

I. Introduction

The successful bidirectional space-to-ground optical communications demonstrations conducted with the Japanese Engineering Test Satellite (ETS-VI) [1,2] will be followed by a series of turn-of-the-century space-to-space and space-to ground demonstrations at data rates ranging from 2 Mb/s to 2.5 Gb/s [3–6]. To support its future optical communications demonstrations, NASA is building a 1-m Optical Communications Telescope Laboratory (OCTL) transceiver station at its Table Mountain Facility in the San Gabriel Mountains of Southern California [7]. TMF is at a 2.29-km elevation and has typical atmospheric seeing of 1.5 to 2.0 arcsec. The telescope is designed as a multipurpose telescope; however, the OCTL's principal function is to support NASA's optical communications technology development and demonstrations. Consequently, the key requirements of the station are to

(1) Conduct communication experiments and demonstrations with laser-bearing spacecraft from low Earth orbit (LEO) to deep space, with an emphasis on deep-space telemetry.

(2) Develop optical spacecraft communications technologies, with an emphasis on deep-space applications, by conducting ground-to-ground, ground-to-LEO, and ground-to-deep-space experiments.

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[1] Communications Systems and Research Section.

The OCTL will support optical communications technology areas, to include

(1) Development of procedures and technologies to enable establishment of handshaking between the spacecraft (S/C) and the ground optical station for initiation of downlink.

(2) Development of procedures for the tracking of deep-space missions by optical telescopes.

(3) Development of back-end electronics systems for reception of downlink from deep-space probes.

(4) Characterization of day-sky and night-sky background under various atmospheric conditions at wavelengths of interest to deep-space communications. This will help in the prediction and design of robust optical-communications links.

(5) Day/night field evaluation of optical components (filters, detectors, etc.) that are critical to optical communications—for example, characterizing the performance of new narrowband filters, testing transmit/receive isolation, and developing techniques such as adaptive optics to narrow the field of view and suppress background light levels.

(6) Characterization of end-to-end space–ground communication links with an emphasis on deep-space telemetry.

(7) Evaluating coding and protocols for robust optical communications applicable to deep-space links.

The building contract has been let to Dumarc Corp., and building construction began in May 1999, with completion by the end of September 1999. The RFP for the telescope has been let to Contraves Brashear, Pittsburg, Pennsylvania. In this article, we describe the developments in the OCTL specification and procurement process that have transpired over the past year. The key OCTL design requirements for optical communications are described in Section II. In Section III, we describe the criteria and process for selecting the building location on the TMF grounds and the results of thermal measurements that dictated the choice of ground cover to surround the building. The results of soil-boring measurements for pier support also are briefly described in this section. The summary is given in Section IV.

II. OCTL Design Requirements

The OCTL is designed to support daytime and nighttime optical communications demonstrations with laser-bearing satellites from LEO to deep-space ranges. These top-level design requirements flowed down as the following requirements to the key subsystems:

Tracking:

(1) The telescope must track with less than 10 μrad line-of-sight rms jitter at frequencies below 20 Hz.

(2) The telescope control software must operate with Tracking and Data Relay satellite, North American Aerospace Defense Command, Global Positioning System, and JPL deep-space predicts.

Optical Train:

(1) The primary mirror is 1 m, excluding the turned edge, and is coated with a protected high-reflectance metal coating.

(2) The reflectance of mirrors M2 through M7 in the near-IR wavelength range must be comparable to that of Denton's FSS-99 high-reflection coating.

(3) All optical surfaces must be of high optical quality to support future adaptive optics work.

(4) The mirror coatings must withstand >10-MW/cm^2 optical power densities.

(5) The telescope must meet all specified performance requirements when pointed within 30 deg of the Sun.

A schematic of the OCTL telescope, dome enclosure, coudé and Cassegrain foci, and laser laboratory area are shown in Fig. 1. The telescope and its pier are supported by the laser laboratory foundation. This foundation in turn is anchored by piers into the bedrock and is vibrationally isolated from the rest of the building. When the dome is open, the telescope and the mirrors in the pier down to M7 at the base of the pier are exposed to the outside temperature to minimize the thermal gradients along the optical train. The pier and its mirrors are thermally isolated from the laser laboratory, and light is optically coupled to and from the telescope via a pair of anti-reflection-coated and wedged sapphire windows.

The building is maintained at a slight positive pressure to minimize the accumulation of dust on optical surfaces. Motors and fans for air exchange are mounted on vibration-damped platforms on floors vibrationally decoupled from the building.

III. OCTL Site Location and Survey

The five sites considered for location of the OCTL at TMF are shown in Fig. 2. Sites 1 and 2 are close to the main buildings and roadways on the site and afforded ready access to telephone, power, water, and snow-removal services during the winter months. Site 1 afforded a 360-deg mask down to below the target elevation of 20 deg with the removal of three trees. Site 2 afforded approximately a 250-deg mask down to below a 20-deg elevation with the removal of two trees. However, 110 deg of the 360-deg field at this site was obscured by building TM-28.

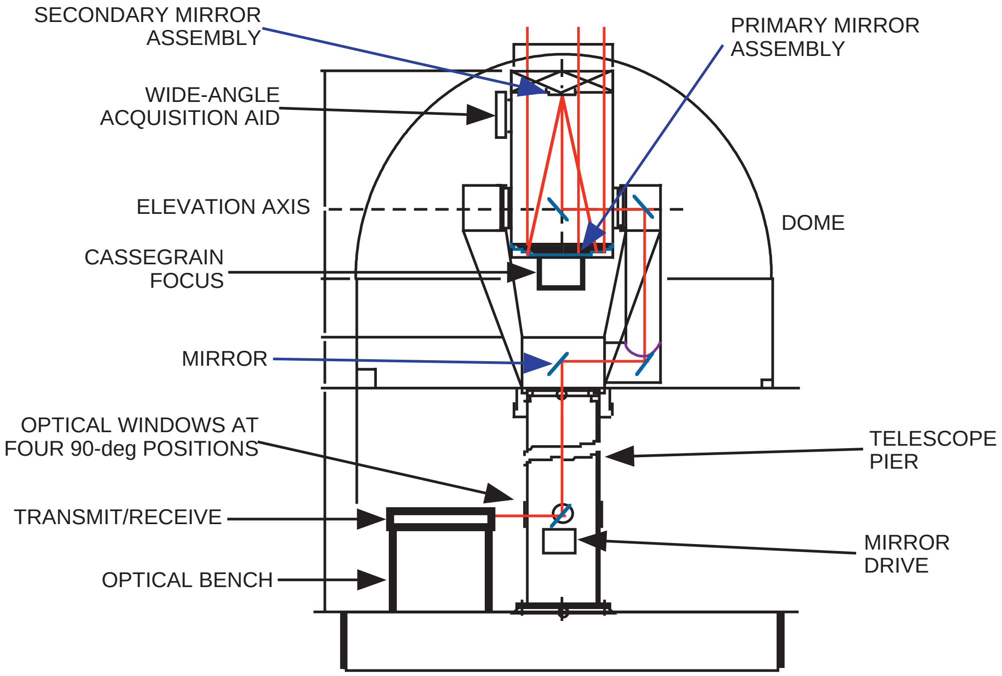

Fig. 1. Schematic of the 1-m telescope with acquisition telescope and dome. The coudé path mirrors and pier also are shown, along with the isolation pad and a laser on an optical bench near the coudé focus. The Cassegrain focus also is shown.

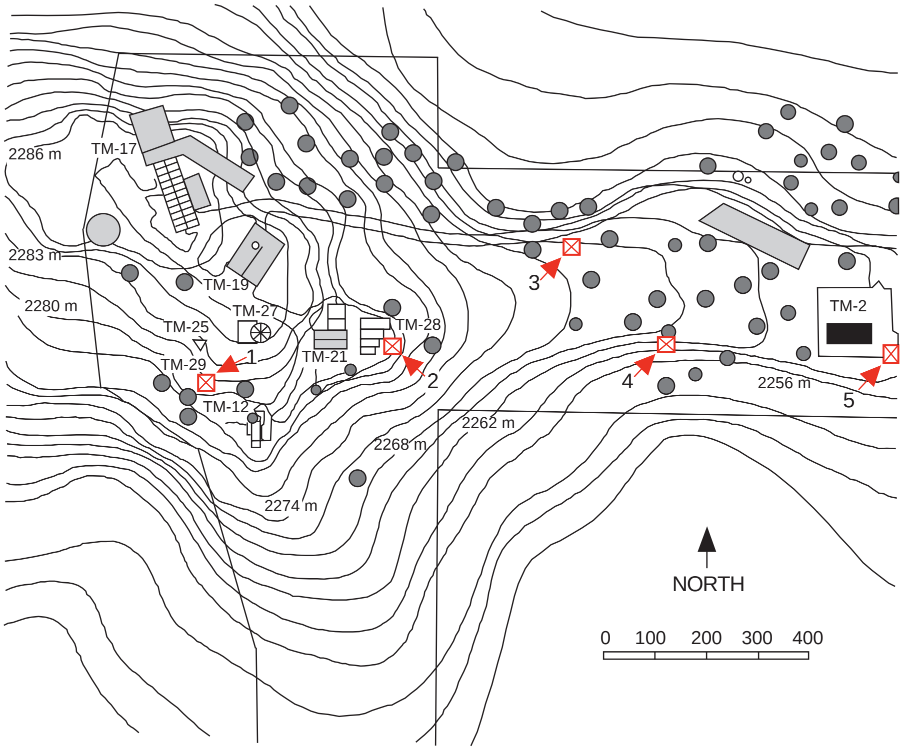

Fig. 2. Topographic map of TMF showing the elevations of the five sites considered for the OCTL. The dark-gray circles represent the locations of pine trees. TM-12 and TM-27 are the transmitter and receiver telescopes, respectively, used during the GOLD experiments. The arrows point to the locations discussed in the text.

Sites 3, 4, and 5 were further removed from the main buildings but close to the main access road. They potentially offered a 360-deg mask down to lower elevations. Sites 3 and 4 offered a 360-deg mask down to a 15-deg elevation with the removal of 6 and 5 trees, respectively. Site 5 offered a 357-deg unobstructed view down to below a 15-deg elevation with the removal of only two trees. The 3-deg loss of field of view was due to obscuration by building TM-2, located approximately 50 m away. Site 5 was located on the only level ground in a steeply graded area. Other sites in this general location were on a steep grade and would have resulted in a significant cost impact to the project.

Site 1 was selected since it best satisfied the key criteria. These were (1) a 360-deg mask down to below a 20-deg elevation, with no obscuration from other buildings on the site and requiring the removal of only three trees, (2) proximity to power, water, and telephone lines on the site, and (3) proximity to regular snow-removal paths. The 20-deg restriction on elevation is in compliance with Federal Aviation Administration (FAA) guidelines for propagation of high-power laser beams. The removal of trees was a key concern of the U.S. Forestry Service, with whom we arranged to replace the removed trees at another location on the site.

Results from boring samples taken at site 1 showed that this surface consisted of sands, gravel, and silty sands to a depth of from 1.5 to 3 m.[2] This surface material was underlaid by bedrock that was composed of granite and weathered metamorphic bedrock, at least down to the maximum boring depth of 6.6 m.

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[2] *Preliminary Geotechnical Engineering Investigation TMF R&D One-Meter Telescope Facility Proposed Telescope Observatory Los Angeles National Forest*, Project 58-7216-01, Kleinfelder, Inc., September 1997.

The San Andreas earthquake fault lies about 1 km to the south-southwest of the selected location. However, a review of geological maps by Kleinfelder, Inc. showed that there were no known earthquake faults traversing or trending towards the site.[3] Thus, the probability of surface rupture during a seismic event is considered low. In addition, the groundwater level is below 6.6 m, making the potential for liquefaction during a seismic event negligible.

It is well-known that the temperature differences between the telescope and the ambient air are the principal cause of degraded seeing in telescopes. To reduce the effects of thermal gradients, the OCTL telescope will be preconditioned so that it will be at the expected ambient temperature at the time of operation. To further reduce the effects of thermal gradients, the grounds around the OCTL building will be covered by asphalt. We measured the thermal lag between the air and the three ground covers: concrete, asphalt, and soil. The results show that the thermal lag is least for the soil and greatest for the concrete. Asphalt will provide a stable surface to access the building for heavy equipment deliveries, while minimizing the temperature gradients and associated turbulence around the facility caused by thermal lag between the ground and the ambient air.

For the thermal lag measurements, all of the temperature sensors were placed in the same general area at TMF. Thermocouples in the concrete and asphalt surfaces were taped in 2-to 5-mm-deep holes and were shaded from direct solar illumination. The thermocouple in the soil was buried approximately 6 mm below the surface. The air thermocouple was located approximately 25 cm above the surface and shaded from direct sunlight. Measurements were taken hourly for a period of 80 hours. During the day, the surface temperatures increased up to 8 deg C above the air temperature, with a 1- to 2-deg C difference between the surfaces. At night, the surfaces cooled to from 2 to 3 deg C below the ambient air, with about a 1-deg C difference between the surfaces.

IV. Summary

We have described the progress made in the development of the NASA/JPL Optical Communications Telescope Laboratory. This laboratory is designed to support the technology development for NASA's optical communications program, including future optical communications demonstrations with spacecraft from LEO to deep-space ranges. The laboratory will be built at NASA's TMF site in the San Gabriel Mountains of Southern California near Wrightwood. Building construction began in May 1999, with completion by September 1999. The contract for the telescope with dome and pier is expected to be let in August of 1999, and first light is expected by the end of the year 2000.

Acknowledgments

We wish to acknowledge the assistance and contributions of J. Lesh, Supervisor of the Optical Communications Group; T. Antoine, C. Simon, H. Shankar, E. Truong, and L. Truong of the JPL Facilities Section; and M. Salsman of the Subcontracts Section. We also acknowledge the contributions of architect R. Santos and his team, who worked closely with the JPL Facilites team to design the building. K. Bartos created the schematic of the telescope and pier; N. Page made the preliminary optical design; and H. Hussein characterized the thermal lag of the soil and other ground cover at TMF. We also acknowledge the assistance of D. Sidwell of TMF and K. Maskew of the JPL Procurement Section.

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