SUB-GB/S LASER-COMMUNICATIONS DOWNLINK FROM MARS.

H. Hemmati, W. H. Farr, A. Biswas, and S. Townes, Jet Propulsion Laboratory, California Institute Technology. 4800 Oak Grove Dr., Pasadena, CA 91109. hhemmati@jpl.nasa.gov

Introduction: Current science instruments for Mars are tailored and constrained by the available telecommunications data-rate capability. Multiple successive and successful validation of laser communications (lasercom) technology from the Earth orbit has shown that this technology can alleviate the data rate constraints. Moreover, spectrum allocation constraints for Ka-band are non-existent at the optical frequencies. For example, 100% of surface of Mars can be mapped during the mission's period, instead of just a few percent, as is done now with the Mars Reconnaissance Orbiter (MRO) spacecraft.

There are sufficient differences between the assembly-level technology requirements for an Earth-orbiting lasercom system and one for deep space communications that at least one demonstration from space of these technologies is warranted prior to operational use. Key differences include: large transmit point-ahead angles, round-trip light-times preventing closed-loop Earth-probe tracking, and simultaneous low *Sun-Probe-Earth* (SPE) and *Sun-Earth-Probe* (SEP) angles leading to low signal-to-noise ratio conditions at both ends of the link. Additionally, operations under the photon-starved regime, as a result of large interplanetary distances, requires highly efficient (high bits/photon) modulation and coding strategies that result in requiring high peak-to-average power laser transmitters that are as yet unproven in the space environment.

Concept: JPL has developed a Mars lasercom system concept that was formally reviewed (at NASA KDPA level) and was targeted to retire the major risks for operational planetary lasercom through a technology demonstration hosted by a Mars orbiting spacecraft. The architecture is scalable to multi-Gb/s data-rates and ranges of at least 10 AU from the Earth (e.g. Jupiter missions). The tracking concept assumes availability of a laser beacon transmitted from Earth to the space terminal.

Since a host platform had not been baselined yet, reasonable assumptions were made for the spacecraft disturbance, a key driver influencing the design of the challenging laser beam pointing control assembly, based on disturbance power spectral densities of past spacecraft. The assumed angular *power spectral density* (PSD) is 1E-7 rad^2/Hz at and below 0.1 Hz; 1E-15 rad^2/Hz at 1 kHz with a 20 dB/decade slope beyond 0.1 Hz. The RMS angular disturbance resulting from this assumed PSD is 140 μrad [1], which is 3 times more severe than measured disturbances on the MRO spacecraft.

A number of downlink data-rates, ranging from < 1 Mb/s to 0.26 Gb/s are supported with the option of implementing paired one-way ranging with a precision of 30 cm. *Direct detection in conjunction with photon-counting* (DD-PC) data reception was selected as more efficient than other options for lasercom terminal's operating conditions [3].

Assuming 4-W average transmit laser power through a 22-cm flight terminal aperture, data-rates on the order of 0.26 Gb/s from 0.25 AU, and 0.1 Gb/s from 0.42 AU are possible to a modest telescope aperture diameter of 5m (Hale telescope at Palomar Mountain). With a larger ground telescope (11.8m LBT in Arizona) the 0.26 Gb/s data-rate can be delivered to Earth from the closest range to Mars (0.42 AU).

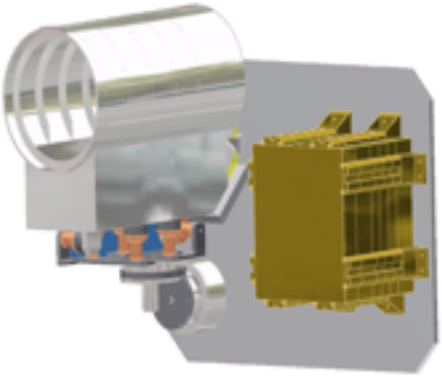

Fig. 1. Schematic of the flight terminal, consisting of a 22-cm transmit/receive telescope on an isolation platform, and an electronics box that also houses the laser transmitter

The flight terminal (Fig. 1) is composed of the three major assemblies:

1. The optical assembly that houses sub-assemblies for the transmit/receive telescope, aft optics, acquisition/ tracking/data sensors, and a point-ahead mirror sub-assembly.
2. A vibration-reduction assembly called the *low-frequency vibration-isolation platform* (LVP) that attenuates the effect of the host spacecraft angular disturbances on the optical assembly to meet the precision pointing requirements. The LVP is designed to mitigate the majority of host-platform-induced angular disturbances, using a hybrid of passive and active isolators, controlled by the processor sub-assembly.
3. The opto-electronic assembly that houses the laser transmitter, modems, controllers, processors and power converters. These sub-assemblies which generate heat are located away from the optical assembly and do not need to be isolated from the host platform vibrations. An umbilical cord containing soft copper and fiberoptic cables connects the optoelectronic assembly to the optical assembly in a fashion that does not interfere with LVP's function [4].

The *Pointing, Acquisition, and Tracking* (PAT) subassembly has to achieve sub-micro-radian (1-σ) transmit beam pointing in the presence of 140 μrad RMS angular disturbance from the spacecraft. Accommodation of the large point-ahead angular range of ±400 μrad is another major PAT design driver.

The *laser transmitter* sub-assembly modulates the input encoded electrical signal onto the transmit laser beam. PPM symbols with 16 to 128 slots per symbol were selected [5]. This modulation scheme requires peak-to-average power ratios ranging from 20:1 to 160:1 from the laser transmitter, and laser pulse-widths ranging from 0.5-ns to 8-ns. *Erbium-doped fiber-amplifier* (EDFA) 1550 nm sources that are presently available commercially deliver significantly lower peak-to-average power ratios than required. The current state of technology (TRL-5), however, makes it reasonable to develop a space-grade laser meeting the requirements. JPL has pursued technology development through SBIRs and funding commercial vendors as a result of which, meeting the laser amplifier requirements is deemed viable.

A 22-cm diameter off-axis Gregorian telescope configuration was selected due to its excellent rejection of the thermal load from the background sunlight during operation at small sun angles. Silicon carbide was selected for the primary mirror substrate and telescope structure to minimize mass and thermal distortion. There are opportunities for multi-functionality of the telescope and the focal plane array with other optical instruments onboard the spacecraft, for example, a high-resolution imager.

References

[1]. A. Biswas, H. Hemmati, S. Piazzolla, B. Moision, K. Birnbaum, and K. Quirk, "Deep-space Optical Terminals (DOT) Systems Engineering," JPL's IPN Progress report 42-183, Nov 15, 2010.

[2]. J. Hamkins, "Pulse position modulation, "Handbook of Computer Networks," H. Bidgoli, Ed. New York Wiley, Ch. 37, 2007.

[3]. B. Moision and J. Hamkins, "Coded modulation for the deep space optical channel: serially concatenated PPM," JPL's IPN Progress Report, vol. 42-161, 2005.

[4]. W. Farr, M. Regehr, M. Wright, D. Shelton, A. Sahasrabudhi, J. Gin, and D. Nguyen, "Overview and trades for the DOT flight laser transmitter," JPL's IPN Progress Report, to be published April 2011.

[5]. K. J. Quirk, J. W. Gin, and M. Srinivasan, "Optical PPM synchronization for photon counting receivers," MILCOM Conference, IEEE, pp.1-7, Nov. 2008.

Acknowledgements: The work described here was performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology under contract with the National Aeronautics and Space administration (NASA).