Adaptive Optics for Daytime Deep Space Laser Communications to Mars

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Abstract: Adaptive optics enables correction for atmospheric turbulence effects and allows reduction in the optical receiver's field-of-view. This reduces sky and planetary background noise and enhances the performance of the daytime deep space optical link.

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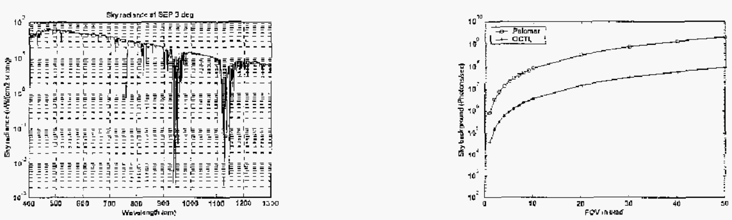
1. Introduction

Meeting the data rates needs of future NASA deep space missions flying with high data rate generating science instruments will require higher carrier frequencies to support the expected demand in communications bandwidth. As a response to this need, NASA is developing deep space optical communications technologies to be demonstrated on the 2009 Mars Laser Communications Demonstration (MLCD)[1,2]. Yet, an operational deep space optical communications ground station network will require strategies be implemented to mitigate the effects of the atmosphere on the optical beam. Cloud cover mitigation strategies are currently under study at JPL, with the exploration of ground station site diversity for a global deep space optical network. Preliminary results show that 90% availability can be realized when the probe has line of sight visibility to stations in a 3-station subnet [3].

The second atmospheric effect, clear air turbulence, can degrade the quality of the optical link particularly in the presence of background noise such as from the daytime sky or a sun-illuminated planet. The time varying turbulence–induced aberrations require a multi-mode receiver with the field-of-view (fov) expanded by as much as 1.53 times the seeing disk to maintain the turbulence-induced link loss to 1-dB [4]. Yet, the larger the fov the greater the background noise at the receiver and the lower signal-to-noise ratio. We have measured the daytime seeing at the JPL OCTL ground station and the results show seeing levels of 5-arcsec, depending on meteorological conditions. This paper describes JPL research in adaptive optics (AO) to reduce the daytime background noise on a Mars-to-Earth optical communications link. AO can reduce atmosphere-induced wavefront aberrations, and enable single mode receiver operation thereby buying back margin in the deep space optical communications link [5].

2. Sky Background and the Optical Link

Realizing the full potential of optical communication will require in addition to nighttime operation, daytime operation sun angles as small as 3 degrees where sky background noise can degrade the quality of the link. Maintaining link quality under these conditions will require combination of spectral and spatial filtering strategies, and higher order pulse position modulation formats.



(a) (b)

Fig. 1: (a) Sky radiance at 3-degree Sun-Earth probe angle for 20 deg, elevation, sun's zenith angle 70±3 deg, clear sky, and 2.2km altitude. (b) Sky background for Hale and OCTL telescopes as a function of FOV for SEP angle of 3 degrees.

Figure 1a shows the sky radiance over the band 400-nm to 1300-nm for a 3 degree sun-Earth-probe angle. A plot of the background levels incident through a 1Åfilter centered at 1064-nm and onto a 1-m and 5-meter aperture is shown as a function of fov in Figure 1b. Figure 2 shows the results of our analysis for a 1064-nm daytime Mars communications link under what we consider to be the best seeing conditions and the best, worst, nominal, and best sky background conditions. Key design parameters of the analysis were: transmitter power 5W, transmitter aperture 30-cm, modulation format 64 pulse position modulation, receiver aperture 5-m, filter bandwidth 1Å, and seeing conditions of 5-urad and 25-urad. The BER plots in the Figures show that with the fov narrowed by an AO system with $d/r_0 = 0.5$ (d is the actuator spacing and r_0 is the Fried coherence length) we can realize gains as high as 8dB under the worst case conditions. The figure shows that up to 3.2 dB improvement can be realized with the implementation of AO. For the worst case seeing (25urad) our results show performance improvement up to 8dB.

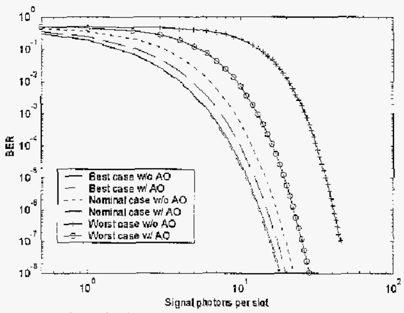


Fig. 2: Daytime BER vs. signal photons for 5-urad seeing. AO gains are 0, 0.8, 3.2 dB.

JPL has built an AO test bed to validate the predicted performance improvement. The system consists on a 97-actuator Xynetics deformable mirror 6 micron stroke and 2-kHz response, a PI tip/tilt sensor, a turbulator built in-house to generate aberrations in the optical path and an integrating sphere to simulate background, a Shack-Hartman wavefront sensor with a low read noise CCD array (3.5e- @ 500frames/sec, and 7e- @ 2000 frames/sec) and 10 sub-apertures across the 1-m telescope pupil. Preliminary laboratory tests using an APD detector with 64 PPM at 10 Mbps data rates show that AO can realize 2 to 3 dB improvement in performance under mild turbulence conditions. Theory predicts performance improvements of 1.2dB to 4.6dB (depending on background noise level) for 64 PPM and low noise photon counting detectors.

3. Conclusion

We have analyzed the benefit of AO to the deep space optical link. Results show that the performance gain increases with turbulence and that several dB performance improvement can be realized. Preliminary laboratory results show AO can realize 2-3 dB performance improvement in the deep space communications link. Future plans are to validate the AO gains with photon counting detectors predicted by theory and to install the AO test bed at the OCTL.

4. Acknowledgements

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5. References

1. B. Edwards, et al. "Overview of the Mars Laser Communications Demonstration Project" Proceedings of AIAA Space Conference and Exposition, Long Beach, CA September 23-35 2003.
2. K. Wilson, B. Parvin, S. Zingales, R. Fugate, P. Kervin, "Optical Ground Station Site Diversity for Deep Space Optical Communications: The Mars Telecom Orbiter Optical Link", AMOS Technical Conference, September 2003, Maui HI.
3. Robert Link, Mary Ellen Craddock, Randall J. Alliss, "Mitigating the Impact of Clouds on Optical Communications", Proceedings of the IEEE Aerospace Conference Big Sky Montana, March 5-12 2005.
4. K. Wilson M. Troy, M. Srinivasan, B. Platt, V. Vilnrotter, M. Wright, V. Garkanian, H. Hemmati, "Daytime Adaptive Optics For Deep Space Optical Communications" Conference proceedings International Space Conference of Pacific-basin Societies (ISCOPS), December 2003 Tokyo, Japan.
5. Shinhak Lee, Keith E. Wilson, and Mitchell Troy, "Background Noise Mitigation in Deep Space Optical Communications using Adaptive Optics" to be published in Special Issue on Optical Communications: IPN PR, Vol.42-161, May 15, 2005.