Simplified Lasercom System Architecture using a Disturbance-Free Platform

Chien-Chung Chen, Hamid Hemmati[1], Abhijit Biswas,
Gerardo Ortiz, William Farr
JPL, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109

Nelson Pedreiro
Lockheed Martin Space Systems, Palo Alto, CA 94304

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ABSTRACT

A simplified laser communications (lasercom) system architecture, primarily for a deep-space flight transceivers, can be realized by decoupling the lasercom optical components from the host spacecraft using a disturbance-free platform (DFP) developed by Lockheed Martin Space System Company. Unlike conventional lasercom system architectures where a high bandwidth control loop is used to stabilize the optical line-of-sight in the presence of platform disturbance, the DFP package isolates the optical train from the high frequency platform jitter produced by the host. By preventing the vibration from coupling into the optics train, the need for a high bandwidth beam stabilization control loop (including fast steering mirror, detectors, controls and the associated relay optics) is eliminated with possible mass savings. Effective isolation of the platform jitter also enables the optical focal plane array to operate at a much longer integration time, thus enabling the use of either faint stars or a weak beacon as a pointing reference. This feature can allow the same lasercom system architecture to be employed for deep space and some near Earth applications, and can potentially enable deep space return signal pointing without the need of an uplink beacon.

1. INTRODUCTION

Laser communications (Lasercom) technology offers the promise of much higher rate data returns while reducing the size and weight of the telecommunications package for deep space missions. This improved system performance is due primarily to the narrow transmit signal beamwidth at the optical wavelength, which allows for more efficient delivery of the transmit signal to the receive aperture. However, because of the narrow beamwidth, pointing control of the lasercom transceiver is much more difficult than, for example, RF systems because of the host spacecraft's attitude uncertainty. Vibration levels are generally several orders of magnitude larger than the required pointing accuracy. Furthermore, the required point-ahead angle to compensate for the cross velocity can also be several orders of magnitude larger than the beamwidth. As a result, the solution to the pointing problem can burden the system's mass and power consumption.

The problem of deep space lasercom beam pointing can in general be decomposed into the problems of stabilizing the optical line of sight and that of providing the appropriate pointing reference to the receiver location. The latter is generally achieved by providing a beacon from the receiver location, and the former is generally achieved by using a high bandwidth control loop to sense and correct for the platform jitter. For a near Earth lasercom system, a strong beacon from the remote transceiver usually serves both purposes. For a deep space lasercom system the required signal power and operational complexity associated with sending a strong beacon to provide stabilization can be challenging. This is because, without an adaptive optics system, the ground based beacon uplink is limited by the atmospheric turbulence to a beam divergence of several tens of microradians. Furthermore, the turbulence introduces undesirable

[1] hamid.hemmati@jpl.nasa.gov

signal fades with a fade period on the order of tens of milliseconds. Finally, safety concerns for aircraft and Earth orbiting spacecraft avoidance can lead to intermittent shut downs that potentially disrupt link operations. Thus it is highly desirable to develop a pointing scheme that does not depend on a strong laser beacon emanated from the Earth to provide the control loop bandwidth.

2. LASERCOM SYSTEM ARCHITECTURE

The current solution to the deep space pointing and tracking, implementation for laser-communications includes the following [1,2]:

a. Limit the amount of high frequency vibration that needs to be corrected using the beacon-pointing loop
b. Use vibration isolators that impede the coupling of higher frequency (>300Hz) disturbance into the system;
c. Stabilize the line of sight against residual high frequency vibrations (2-300 Hz) of the optical system using inertial reference sensors. For example, by using a magneto-hydrodynamic inertial reference unit (MIRU).
d. Use an Earth image tracker to provide lower frequency tracking;
e. Use an Earth-based beacon signal to indicate the precise location of the receive transceiver.

The solution, while achieving the required pointing performance, drives the lasercom system architecture, size, mass, and power. An alternative solution, as described here, accomplishes the deep space pointing by limiting the amount of jitter that is coupled into the optical communications payload using a disturbance-free platform (DFP) developed by the Lockheed Martin Space Systems Company [3-5]. In a DFP-based lasercom system, the optical payload is isolated from the spacecraft through a 6 degrees-of-freedom non-contact actuator (e.g. voice coils). Under nominal zero-g environment, the payload is "free flying" relative to the spacecraft and there is no mechanical coupling between the spacecraft and the payload except through the power harness, data cables and and optical fibers. If payload pointing is necessary, the voice coils are actuated against the spacecraft, and provide a very low coupling between the spacecraft and the optical payload. The low coupling constant results in a high level of vibration isolation between the spacecraft and the optical communications payload. A second control loop, closed around the position sensor and the spacecraft attitude control system (ACS), moves the payload away from the spacecraft such that there will be no mechanical contact between them. Figure 1 shows a conceptual block diagram of the DFP system. The measured performance at the laboratory testbed, as shown in Figure 2, demonstrates an effective isolation in excess of 60 dB.

By reducing the amount of vibration that is coupled into the lasercom payload, the pointing control problem of the lasercom system can be significantly simplified by eliminating the need for a high bandwidth pointing stabilization loop. Instead, the flight payload only needs to provide a low bandwidth sensor that ustilizes a pointing reference for locating the receiver. The latter can be implemented using a wide field-of-view (FOV) sensor array (e.g. a CCD detector). A lasercom system using the above principle is shown in Figure 3. Unlike conventional optical communication systems that require up to two steering elements (a fast steering mirror to stabilize the line of sight, and a point ahead mirror), there is no steering element in the optical train. Steering is primarily provided by the DFP platform, which can be controlled in all 6 degrees of freedom relative to the spacecraft. For FOV constrained systems, an actuated fiber, transmitting the laser signal, can provide the necessary point-ahead angles.

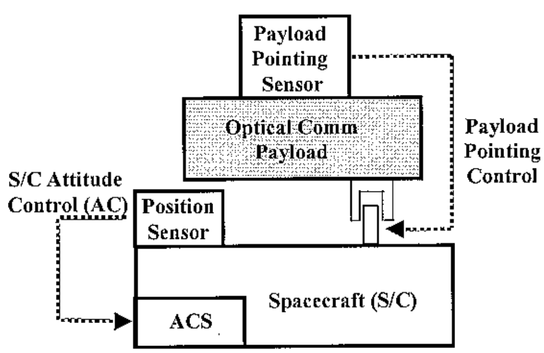

Figure 1. Concept of a DFP system showing a payload pointing control loop closing around the non-contact actuator and a s/c control loop which prevents mechanical contact between the s/c and the payload.

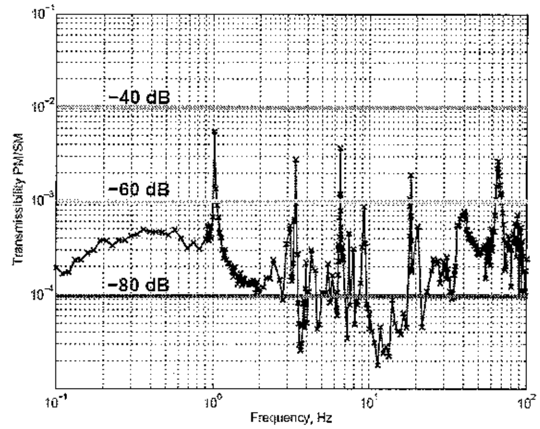

Figure 2. Measured rejection performance from the Lockheed-Martin testbed

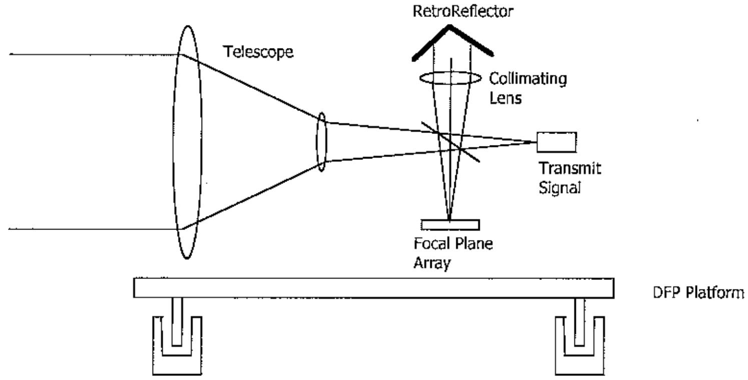

Figure 3. Concept of a simplified lasercom system without the need for a line-of-sight stabilization control loop

Pointing control for the DFP-stabilized lasercom system works as follows: The focal plane array images the field of view where either the ground based beacon or the celestial background provides an attitude reference of the lasercom system line-of-sight. A portion of the transmit signal is also imaged onto the focal plane using a retro-reflector (see Figure 3 and 5a), which indicates the direction where the transmit signal is pointed relative to the image on the focal plane. Given the celestial background, one can deduce where the transmit signal needs to be pointed, and an error signal can be generated which controls the DFP to point the payload such that the transmit signal falls on the desired location. Shown in Figure 4 is a concept of a typical focal plane image using reference stars as a pointing reference. Note that the celestial reference could also be the sun-lit Earth image.

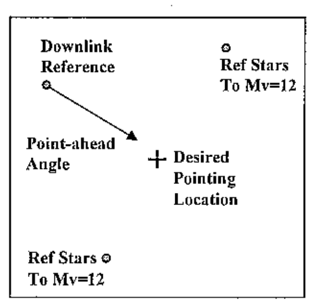

Figure 4. Typical focal plane images showing the celestial background and the direction of the transmit signal.

A conceptual design of a DFP-enabled lasercom transceiver is shown in Figures 5b and 5c below. The system includes an optical transceiver assembly located on top of the 6 degrees of freedom DFP platform. The remaining elements for the lasercom system including auxiliary electronics, the control processor, laser master oscillator, data formatter, power converter, DFP drive electronics, and a separately packaged fiber amplifier.

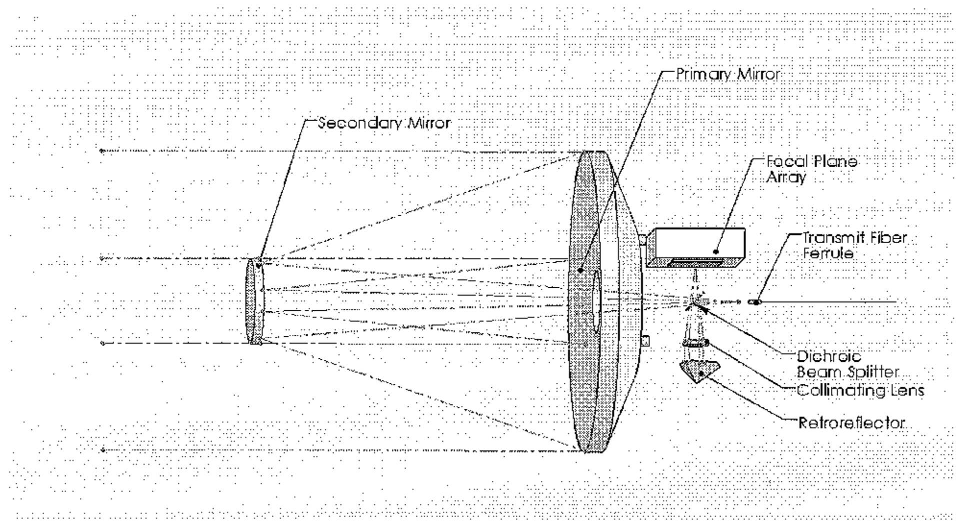

Figure 5a: Conceptual design of a lasercom optics

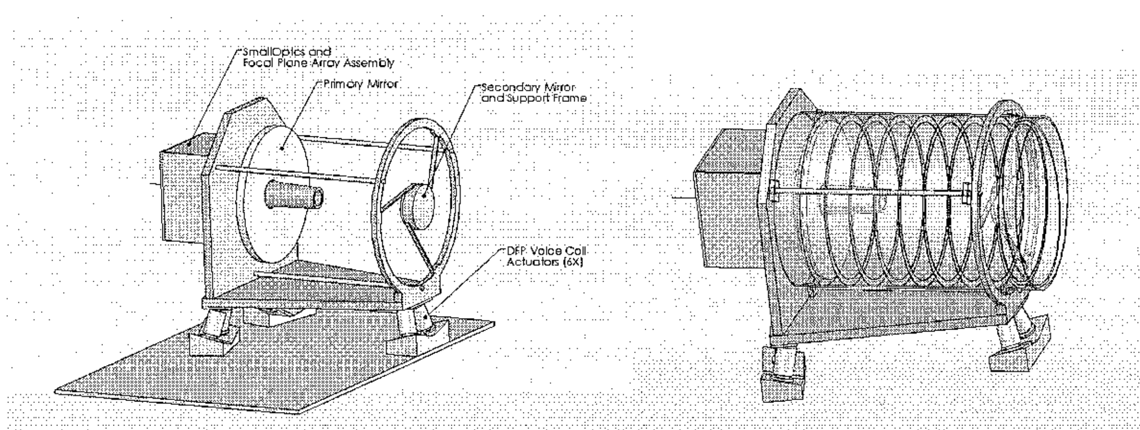

Figure 5b: Lasercom optics located on the DFP platform

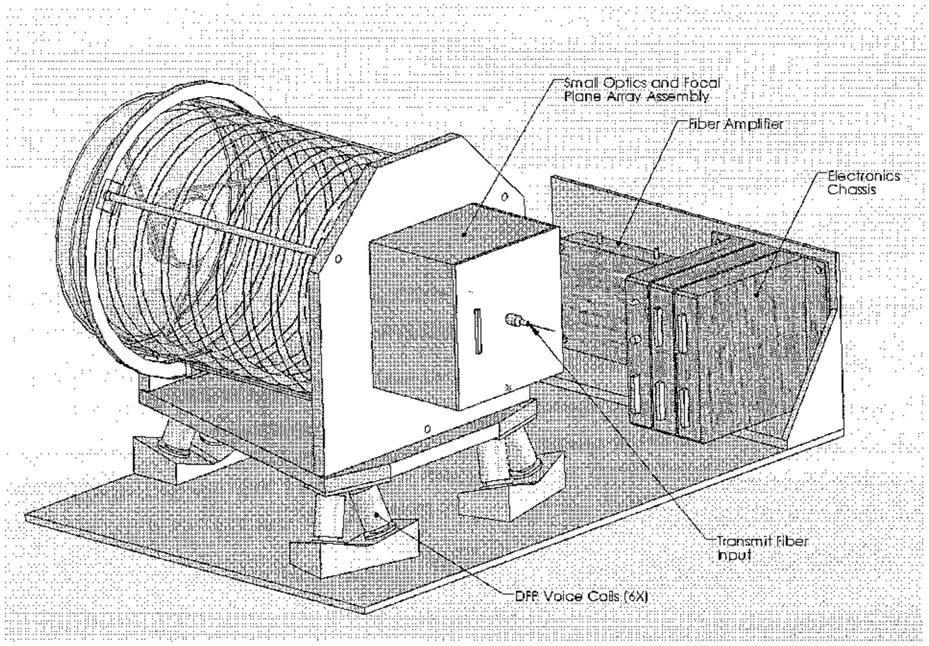

Figure 5c. Concept of the Lasercom package with a DFP-isolated optics module, a separate electronics and an external fiber amplifier

2.1 Advantages

The advantages of this approach, compared to the conventional designs, include:

a. By reducing the amount of LOS jitter coupled into the optical element, the focal plane array can be integrated over a much longer period of time. This enables the use of faint beacon as pointing references. Because of the long integration time, the pointing concept is insensitive to the scintillation-induced fades of the uplink beacon. Also, the long integration time may enable the use of faint celestial objects (stars, etc.) as a pointing reference.

b. By allowing the lasercom system to point with a faint beacon and/or weak stars, the same lasercom system architecture can be employed for both the deep space flight transceivers and some near-Earth transceivers.

c. In addition to providing mechanical isolation, the DFP package can also provide coarse and fine pointing adjustment The former relaxes the spacecraft pointing requirement

d. By eliminating the need for high bandwidth line of sight control, the optical package can be significantly simplified and some light-weighting is expected. At least one high bandwidth beam steering element can be eliminated from the optical train. This reduces both the mass of the steering element(s), the drive electronics, the mechanical stiffening required to handle the motion of the steering element(s), and relaxes the requirements for, and therefore the reduces the mass associated with, passive isolators for the transceiver.
   - By eliminating the relay optics and intermediate pupil planes, one can reduce the complexity of the optical design and the mass associated with the small optics.

e. In addition to the reduced system complexity, there is also a potential reduction of power consumption that can be obtained from (a) elimination of the high bandwidth drive and control for the fast steering elements, (b) elimination of the inertial sensor for inertial stabilization, and (c) reducing the bandwidth and readout rate of the focal plane.

CONCLUSIONS

A significant simplification of the lasercom system architecture can be realized by mounting the lasercom optics on a disturbance-free platform (DFP). Unlike conventional lasercom system architecture where a high bandwidth steering mirror control loop is used to stabilize the optics line-of-sight in the presence of platform disturbance, the DFP package isolates the optical train from the high frequency platform jitter of the host spacecraft. This effectively prevents the vibration from coupling into the optics train, and eliminating the need for a high bandwidth control loop. The resulting system architecture simplification can lead to simplifying pointing and operating an optical communications transceiver almost independent of other spacecraft operations. Depending on development of the DFP mass and power savings may be realizable compared to the current laser-communication architectures.

Effective isolation of the platform jitter also enables the optical focal plane array to operate at a much longer integration time, thus enabling it to image faint stars and weak uplink beacon. This will allow the same lasercom system architecture to be employed for both deep space and some near Earth applications. With a sufficiently large field of view, this architecture may also enable the deep space transceiver to use only the stellar background as the pointing reference, thereby eliminating the need for an uplink beacon and thus significantly simplifying the operational complexity associated with managing a high power beacon uplink.

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