

## Simplified Optics and Controls for Laser Communications

NASA's Jet Propulsion Laboratory, Pasadena, California

A document discusses an architecture of a spaceborne laser communication system that provides for a simplified control subsystem that stabilizes the line of sight in a desired direction. Heretofore, a typical design for a spaceborne laser communication system has called for a high-bandwidth control loop, a steering mirror and associated optics, and a fast steering-mirror actuator to stabilize the line of sight in the presence of vibrations. In the present architecture, the need for this fast

steering-mirror subsystem is eliminated by mounting the laser-communication optics on a disturbance-free platform (DFP) that suppresses coupling of vibrations to the optics by  $\geq 60$  dB. Taking advantage of microgravity, in the DFP, the optical assembly is free-flying relative to the rest of the spacecraft, and a low-spring-constant pointing control subsystem exerts small forces to regulate the position and orientation of the optics via voice coils. All steering is effected via the DFP, which can

be controlled in all six degrees of freedom relative to the spacecraft. A second control loop, closed around a position sensor and the spacecraft attitude-control system, moves the spacecraft as needed to prevent mechanical contact with the optical assembly.

*This work was done by Chien-Chung Chen and Hamid Hemmati of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-42693*

## Coherent Detection of High-Rate Optical PPM Signals

Quantum-limited performance is achievable.

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A method of coherent detection of high-rate pulse-position modulation (PPM) on a received laser beam has been conceived as a means of reducing the deleterious effects of noise and atmospheric turbulence in free-space optical communication using focal-plane detector array technologies. In comparison with a receiver based on direct detection of the intensity modulation of a PPM signal, a receiver based on the present method of coherent detection performs well at much higher background levels.

In principle, the coherent-detection receiver can exhibit quantum-limited performance despite atmospheric tur-

bulence. The key components of such a receiver include standard receiver optics, a laser that serves as a local oscillator, a focal-plane array of photodetectors, and a signal-processing and data-acquisition assembly needed to sample the focal-plane fields and reconstruct the pulsed signal prior to detection. The received PPM-modulated laser beam and the local-oscillator beam are focused onto the photodetector array, where they are mixed in the detection process. The two lasers are of the same or nearly the same frequency. If the two lasers are of different frequencies, then

the coherent detection process is characterized as heterodyne and, using traditional heterodyne-detection terminology, the difference between the two laser frequencies is denoted the intermediate frequency (IF). If the two laser beams are of the same frequency and remain aligned in phase, then the coherent detection process is characterized as homodyne (essentially, heterodyne detection at zero IF).

As a result of the inherent squaring operation of each photodetector, the output current includes an IF component that contains the signal modulation. The amplitude of the IF component is proportional to the product of the local-oscillator signal amplitude and the PPM signal amplitude. Hence, by using a sufficiently strong local-oscillator signal, one can make the PPM-modulated IF signal strong enough to overcome thermal noise in the receiver circuits: this is what makes it possible to achieve near-quantum-limited detection in the presence of strong background.

Following quantum-limited coherent detection, the outputs of the individual photodetectors are automatically aligned in phase by use of one or more adaptive array compensation algorithms [e.g., the least-mean-square (LMS) algorithm]. Then the outputs are combined and the resulting signal is processed to extract the high-rate information, as though the PPM signal were received by a single photodetector.

In a continuing series of experiments

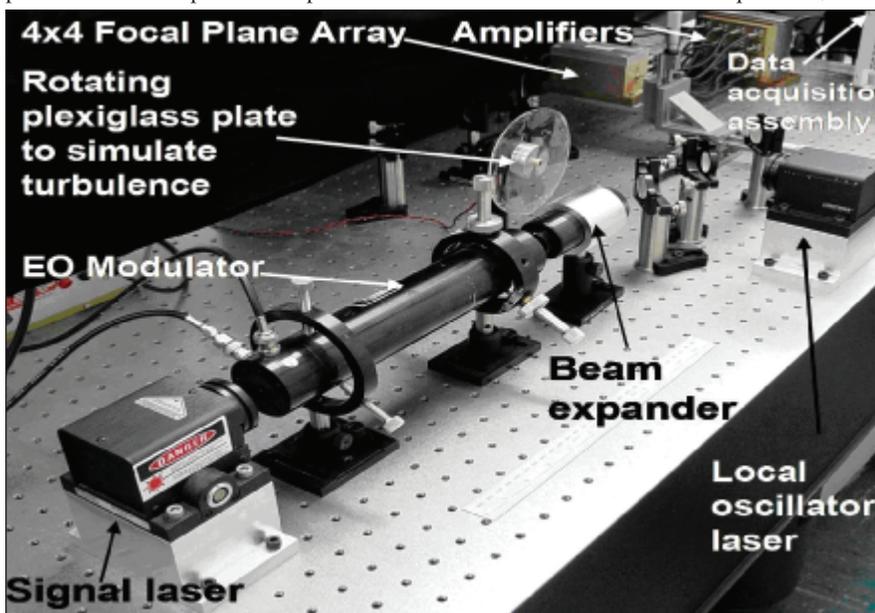


Figure 1. A Coherent Optical Receiver as it is set up for experiments at NASA's Jet Propulsion Laboratory.

to test this method (see Fig. 1), the local oscillator has a wavelength of 1,064 nm, and another laser is used as a signal transmitter at a slightly different wavelength to establish an IF of about 6 MHz. There are 16 photodetectors in a 4x4 focal-plane array; the detector outputs are digitized at a sampling rate of 25 MHz, and the signals in digital form are combined by use of the LMS algorithm. Convergence of the adaptive combining algorithm in the presence of

simulated atmospheric turbulence for optical PPM signals has already been demonstrated in the laboratory; the combined output is shown in Fig. 2(a), and Fig. 2(b) shows the behavior of the phase of the combining weights as a function of time (or samples). We observe that the phase of the weights has a sawtooth shape due to the continuously changing phase in the down-converted output, which is not exactly at zero frequency.

Detailed performance analysis of this coherent free-space optical communication system in the presence of simulated atmospheric turbulence is currently under way.

*This work was done by Victor Vilnrotter and Michela Muñoz Fernández of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-40974*

## Multichannel Phase and Power Detector

Purposes served by this system include beam steering and power combining.

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An electronic signal-processing system determines the phases of input signals arriving in multiple channels, relative to the phase of a reference signal with which the input signals are known to be coherent in both phase and frequency. The system also gives an estimate of the power levels of the input signals. A prototype of the system has four input channels that handle signals at a frequency of  $\approx 9.5$  MHz, but the basic principles of design and operation are extensible to other signal frequencies and greater numbers of channels.

The prototype system consists mostly of three parts:

- An analog-to-digital-converter (ADC) board, which coherently digitizes the input signals in synchronism with the reference signal and performs some simple processing;
- A digital signal processor (DSP) in the form of a field-programmable gate

array (FPGA) board, which performs most of the phase- and power-measurement computations on the digital samples generated by the ADC board; and

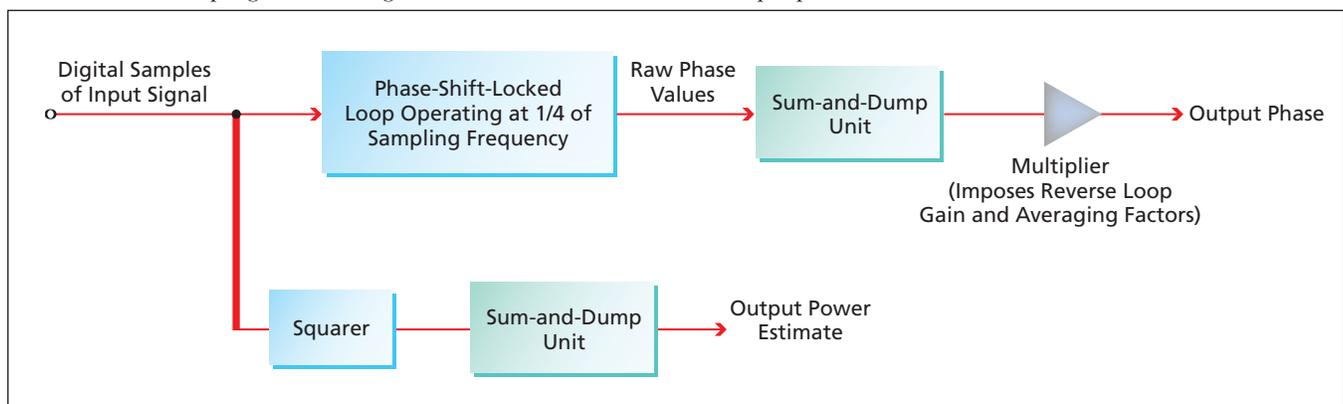
- A carrier board, which allows a personal computer to retrieve the phase and power data.

The DSP contains four independent phase-only tracking loops, each of which tracks the phase of one of the pre-processed input signals relative to that of the reference signal (see figure). The phase values computed by these loops are averaged over intervals, the length of which is chosen to obtain output from the DSP at a desired rate. In addition, a simple sum of squares is computed for each channel as an estimate of the power of the signal in that channel.

The relative phases and the power level estimates computed by the DSP could be used for diverse purposes in

different settings. For example, if the input signals come from different elements of a phased-array antenna, the phases could be used as indications of the direction of arrival of a received signal and/or as feedback for electronic or mechanical beam steering. The power levels could be used as feedback for automatic gain control in preprocessing of incoming signals. For another example, the system could be used to measure the phases and power levels of outputs of multiple power amplifiers to enable adjustment of the amplifiers for optimal power combining.

*This work was done by Samuel Li, James Lux, Robert McMaster, and Amy Boas of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
NPO-42697*



A Functional Block Diagram of the DSP shows one channel. The other channels are identical.