

the counters are sampled and cleared. This downsampled photon count information is then sent one counter word at a time to the GA.

For a large array, processing even the downsampled pixel counts exceeds the capabilities of the GA. Windowing of the array, whereby several subsets of pixels are designated for processing, is used to further reduce the computational requirements. The grouping of the designated pixel frame as the photon count information is sent one word at a time to

the GA, the aggregation of the pixels in a window can be achieved by selecting only the designated pixel counts from the serial stream of photon counts, thereby obviating the need to store the entire frame of pixel count in the gate array. The pixel count sequence from each window can then be processed, forming lower-rate pixel statistics for each window. By having this processing occur in the GA rather than in the ASIC, future changes to the processing algorithm can be readily implemented.

The high-bandwidth requirements of a photon counting array combined with the properties of the optical modulation being detected by the array present a unique problem that has not been addressed by current CCD or CMOS sensor array solutions.

*This work was done by Ferze D. Patawaran, William H. Farr, Danh H. Nguyen, Kevin J. Quirk, and Adit Sahasrabudhe of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48346*

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## Optical Phase Recovery and Locking in a PPM Laser Communication Link

**Coherence augmentation in a pulsed optical communication link will enable enhanced Doppler tracking and ranging capabilities.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Free-space optical communication holds great promise for future space missions requiring high data rates. For data communication in deep space, the current architecture employs pulse position modulation (PPM). In this scheme, the light is transmitted and detected as pulses within an array of time slots. While the PPM method is efficient for data transmission, the phase of the laser light is not utilized.

The phase coherence of a PPM optical signal has been investigated with the goal of developing a new laser communication and ranging scheme that utilizes optical coherence within the established PPM architecture and photon-counting detection (PCD). Experimental measurements of a PPM modulated optical signal were conducted, and modeling code was developed to generate random PPM signals and simulate spectra via FFT (Fast Fourier Transform) analysis. The experimental

results show very good agreement with the simulations and confirm that coherence is preserved despite modulation with high extinction ratios and very low duty cycles.

A real-time technique has been developed to recover the phase information through the mixing of a PPM signal with a frequency-shifted local oscillator (LO). This mixed signal is amplified, filtered, and integrated to generate a voltage proportional to the phase of the modulated signal. By choosing an appropriate time constant for integration, one can maintain a phase lock despite long "dark" times between consecutive pulses with low duty cycle. A proof-of-principle demonstration was first achieved with an RF-based PPM signal and test setup. With the same principle method, an optical carrier within a PPM modulated laser beam could also be tracked and recovered. A reference laser was phase-locked to an independ-

ent pulsed laser signal with low-duty-cycle pseudo-random PPM codes. In this way, the drifting carrier frequency in the primary laser source is tracked via its phase change in the mixed beat note, while the corresponding voltage feedback maintains the phase lock between the two laser sources.

The novelty and key significance of this work is that the carrier phase information can be harnessed within an optical communication link based on PPM-PCD architecture. This technology development could lead to quantum-limited efficient performance within the communication link itself, as well as enable high-resolution optical tracking capabilities for planetary science and spacecraft navigation.

*This work was done by David C. Aveline, Nan Yu, and William H. Farr of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47994*

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## High-Speed Edge-Detecting Line Scan Smart Camera

**This circuit reduces size and system complexity while increasing processing frame rates.**

*John H. Glenn Research Center, Cleveland, Ohio*

A high-speed edge-detecting line scan smart camera was developed. The camera is designed to operate as a component in a NASA Glenn Research Center developed inlet shock detection system. The inlet shock is detected by projecting

a laser sheet through the airflow. The shock within the airflow is the densest part and refracts the laser sheet the most in its vicinity, leaving a dark spot or shadowgraph. These spots show up as a dip or negative peak within the pixel inten-

sity profile of an image of the projected laser sheet. The smart camera acquires and processes in real-time the linear image containing the shock shadowgraph and outputting the shock location. Previously a high-speed camera