

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

and personal computer would perform the image capture and processing to determine the shock location.

This innovation consists of a linear image sensor, analog signal processing circuit, and a digital circuit that provides a numerical digital output of the shock or negative edge location. The smart camera is capable of capturing and processing linear images at over 1,000 frames per second. The edges are identi-

fied as numeric pixel values within the linear array of pixels, and the edge location information can be sent out from the circuit in a variety of ways, such as by using a microcontroller and onboard or external digital interface to include serial data such as RS-232/485, USB, Ethernet, or CAN BUS; parallel digital data; or an analog signal. The smart camera system can be integrated into a small package with a relatively small number of

parts, reducing size and increasing reliability over the previous imaging system.

*This work was done by Norman F. Prokop of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18816-1.*

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## Optical Communications Channel Combiner

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

NASA has identified deep-space optical communications links as an integral part of a unified space communication network in order to provide data rates in excess of 100 Mb/s. The distances and limited power inherent in a deep-space optical downlink necessitate the use of photon-counting detectors and a power-efficient modulation such as pulse position modulation (PPM). For the output of each photodetector, whether from a separate telescope or a portion of the detection area, a communication receiver estimates a log-likelihood ratio for each PPM slot. To realize the full effective aperture of these receivers, their outputs must be combined prior to information decoding.

A channel combiner was developed to synchronize the log-likelihood ratio (LLR) sequences of multiple receivers, and then combines these into a single LLR sequence for information decoding. The channel combiner synchronizes the LLR sequences of up to three receivers and then combines these into a single LLR sequence for output. The channel combiner has three channel inputs, each of which takes as input a sequence of four-bit LLRs for each PPM slot in a codeword via a XAUI 10 Gb/s quad optical fiber interface. The cross-correlation between the channels' LLR time series are calculated and used to synchronize the sequences prior to combining. The output of the

channel combiner is a sequence of four-bit LLRs for each PPM slot in a codeword via a XAUI 10 Gb/s quad optical fiber interface. The unit is controlled through a 1 Gb/s Ethernet UDP/IP interface.

A deep-space optical communication link has not yet been demonstrated. This ground-station channel combiner was developed to demonstrate this capability and is unique in its ability to process such a signal.

*This work was done by Kevin J. Quirk, Jonathan W. Gin, Danh H. Nguyen, and Huy Nguyen of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact [iaoffice@jpl.nasa.gov](mailto:iaoffice@jpl.nasa.gov). NPO-47733*

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## Development of Thermal Infrared Sensor To Supplement Operational Land Imager

**The application is for the Landsat Data Continuity Mission.**

*Goddard Space Flight Center, Greenbelt, Maryland*

The thermal infrared sensor (TIRS) is a quantum well infrared photodetector (QWIP)-based instrument intended to supplement the Operational Land Imager (OLI) for the Landsat Data Continuity Mission (LDCM). The TIRS instrument is a far-infrared imager operating in the pushbroom mode with two IR channels: 10.8 and 12  $\mu\text{m}$ . The focal plane will contain three 640x512 QWIP arrays mounted onto a silicon substrate. The readout integrated circuit (ROIC) addresses each pixel on the QWIP arrays and reads out the pixel value (signal). The ROIC is controlled by the focal plane electronics (FPE) by

means of clock signals and bias voltage value. The means of how the FPE is designed to control and interact with the TIRS focal plane assembly (FPA) is the basis for this work.

The technology developed under the FPE is for the TIRS focal plane assembly (FPA). The FPE must interact with the FPA to command and control the FPA, extract analog signals from the FPA, and then convert the analog signals to digital format and send them via a serial link (USB) to a computer. The FPE accomplishes the described functions by converting electrical power from generic power supplies to the required bias

power that is needed by the FPA. The FPE also generates digital clocking signals and shifts the typical transistor-to-transistor logic (TTL) to  $\pm 5$  V required by the FPA. The FPE also uses an application-specific integrated circuit (ASIC) named System Image, Digitizing, Enhancing, Controlling, And Retrieving (SIDEAR) from Teledyne Corp. to generate the clocking patterns commanded by the user. The uniqueness of the FPE for TIRS lies in that the TIRS FPA has three QWIP detector arrays, and all three detector arrays must be in synchronization while in operation. This is to avoid data skewing while observing