Physical Sciences

Photon Counting Using Edge-Detection Algorithm

Improved optical communications links can be used in building-to-building networks in high-attenuation conditions such as rain or fog.

NASA's Jet Propulsion Laboratory, Pasadena, California

New applications such as high-data-rate, photon-starved, free-space optical communications require photon counting at flux rates into gigaphoton-per-second regimes coupled with subnanosecond timing accuracy. Current single-photon detectors that are capable of handling such operating conditions are designed in an array format and produce output pulses that span multiple sample times. In order to discern one pulse from another and not to over-count the number of incoming photons, a detection algorithm must be applied to the sampled detector output pulses. As flux rates increase, the ability to implement such a detection algorithm becomes difficult within a digital processor that may reside within a field-programmable gate array (FPGA).

Systems have been developed and implemented to both characterize gigahertz bandwidth single-photon detectors, as well as process photon count signals at rates into gigaphotons per second in order to implement communications links at SCPPM (serial concatenated pulse position modulation) encoded data rates exceeding 100 megabits per second with efficiencies greater than two bits per detected photon.

A hardware edge-detection algorithm and corresponding signal combining and deserialization hardware were developed to meet these requirements at sample rates up to 10 GHz. The photon discriminator deserializer hardware board accepts four inputs, which allows for the ability to take inputs from a quadphoton counting detector, to support requirements for optical tracking with a reduced number of hardware components. The four inputs are hardware leading-edge detected independently. After leading-edge detection, the resultant samples are "ORed" together prior to deserialization. The deserialization is performed to reduce the rate at which data is passed to a digital signal processor, perhaps residing within an FPGA.

The hardware implements four separate analog inputs that are connected through RF connectors. Each analog input is fed to a high-speed 1-bit comparator, which digitizes the input referenced to an adjustable threshold value. This results in four independent serial sample streams of binary 1s and 0s, which are ORed together at rates up to 10 GHz. This single serial stream is then deserialized by a factor of 16 to create 16 signal lines at a rate of 622.5 MHz or lower for input to a high-speed digital processor assembly.

The new design and corresponding hardware can be employed with a quad-photon counting detector capable of handling photon rates on the order of multi-gigaphotons per second, whereas prior art was only capable of handling a single input at 1/4 the flux rate. Additionally, the hardware edge-detection algorithm has provided the ability to process 3–10× higher photon flux rates than previously possible by removing the limitation that photon-counting detector output pulses on multiple channels being ORed not overlap. Now, only the leading edges of the pulses are required to not overlap. This new photon counting digitizer hardware architecture supports a universal front end for an optical communications receiver operating at data rates from kilobits to over one gigabit per second to meet increased mission data volume requirements.

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Holographic Vortex Coronagraph

This apparatus offers potential advantages of performance and manufacturability over conventional coronagraphs.

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A holographic vortex coronagraph (HVC) has been proposed as an improvement over conventional coronagraphs for use in high-contrast astronomical imaging for detecting planets, dust disks, and other broadband light scatterers in the vicinities of stars other than the Sun. Because such light scatterers are so faint relative to their parent stars, in order to be able to detect them, it is necessary to effect ultra-high-contrast (typically by a factor of the order of 10^{10}) suppression of broadband light from the stars. Unfortunately, the performances of conventional coronagraphs are limited by low throughput, dispersion, and difficulty of satisfying challenging manufacturing requirements. The HVC concept offers the potential to overcome these limitations.

A key feature of any coronagraph is an occulting mask in the image plane of a telescope, centered on the optical axis of the telescope. In a conventional coronagraph, the occulting mask is an opaque amplitude mask that obstructs the central starlight when the optical axis points toward the star in question. In the HVC, the occulting mask is a holographic vortex grating, which may be created by etching or otherwise forming the interference pattern of a helical phase ramp and a plane wave beam into