



# Partitioned-Interval Quantum Optical Communications Receiver

The receiver structure described here improves upon the performance of optical communications links, achieving high sensitivity and high data rates even with extremely weak optical signals.

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The proposed quantum receiver in this innovation partitions each binary signal interval into two unequal segments: a short "pre-measurement" segment in the beginning of the symbol interval used to make an initial guess with better probability than 50/50 guessing, and a much longer segment used to make the high-sensitivity signal detection via field-cancellation and photon-counting detection. It was found that by assigning as little as 10% of the total signal energy to the pre-measurement segment, the initial 50/50 guess can be improved to about 70/30, using the best available measurements such as classical coherent or "optimized Kennedy" detection.

However, 70% detection probability (or, equivalently, 30% error probability) is not good enough for communications, even with the most powerful codes, which require error probabilities in the 0.01–0.1 range to achieve the desired coded performance. Due to the requirement to maintain a constant-envelope local laser field, the recently

reported "optimized Kennedy" measurement was selected for making this initial guess. The outcome of this first measurement is used to decide which signal the receiver should try to null. Hence, the local field envelope and phase are adjusted to nearly cancel the more likely signal, and photon counting is used for the rest of the interval to confirm this initial decision. If the wrong signal is selected initially, then the local laser adds instead of subtracting a constant matched laser field to the received signal, yielding a higher probability error; that is, higher probability of erroneously pre-selecting the "other" binary signal. Optimum partitioning of the signal interval is critical, and must be carried out for each new value of  $K_s$ . This concept can be extended directly to more than two intervals, by partitioning the first interval itself into two segments, optimized for the smaller initial energy, to further improve the "pre-measurement" upon which the final high-sensitivity measurement strategy is based.

The performance gain of the partitioned-interval quantum receiver over the well-known Kennedy receiver detection strategy is shown in Figure 2, along with the gains of the classical coherent receiver and the optimized Kennedy receiver. It is noted that the coherent receiver peaks at an average received photon-count of  $K_s = 0.095$  attaining a maximum gain of 1.272 over the Kennedy receiver, whereas the optimized Kennedy receiver peaks at  $K_s = 0.165$ , with a maximum gain of 1.381, after which both gains decrease as the average signal energy increases: the optimized Kennedy receiver approaches 1 at high signal energies, reverting back to the conventional Kennedy receiver, whereas the coherent receiver continues towards zero. However, the partitioned-interval receiver described here attains higher gains, and tends to maintain these gains near their maximum value even with increasing signal energy.

The only receiver structure known to achieve the quantum limit theoretically

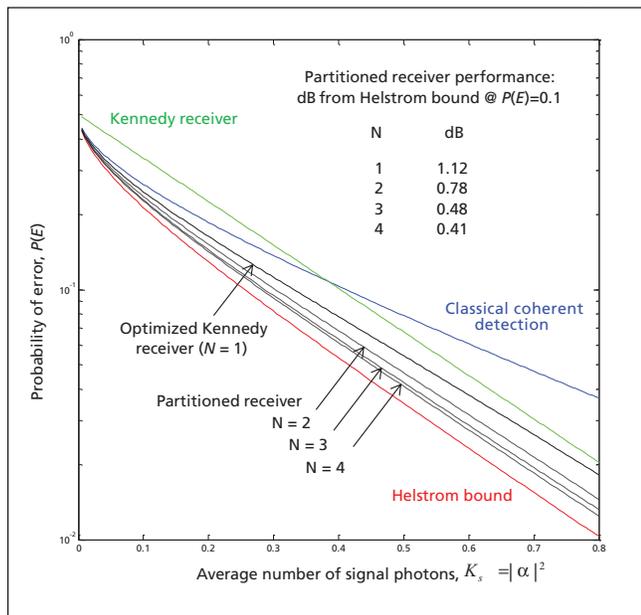


Figure 1. Error Probability Performance and comparison of  $N$ -segment partitioned receivers.

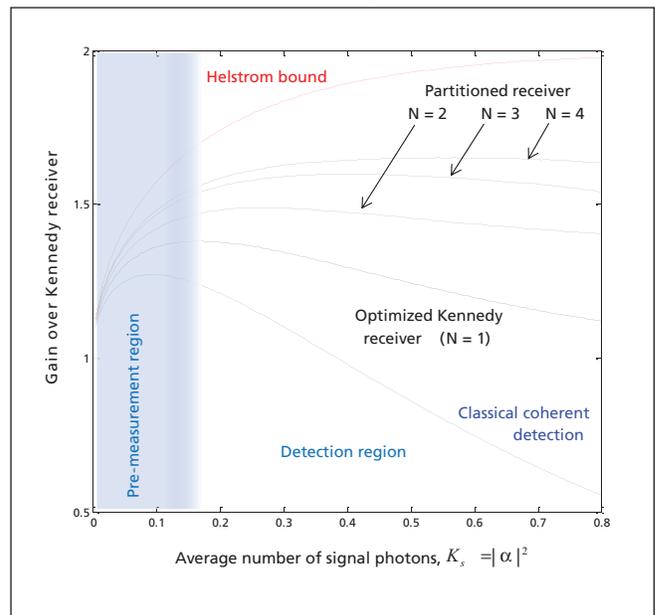


Figure 2. Gain of Coherent, Optimized Kennedy and partitioned receivers over Kennedy receiver.

on binary signal detection (the curves labeled “Helstrom bound” in Figures 1 and 2) is known as the Dolinar receiver. This approach applies a rapidly time-varying local laser field to the signal during each bit-interval, but such time-varying fields are difficult to generate in practice at high data rates. In addition, the phase and sign of the local laser fields must be switched instantaneously with the detection of each new photon for best performance, placing significant burdens on the processing speed of the receiver and on the response of the local laser. The proposed solution over-

comes these problems by employing constant local laser intensities that can be pre-computed based on estimates of signal-strength, while attaining nearly the same bit-error rate as the more complex quantum-optimum receiver. The solution proposed here will therefore enable high-sensitivity deep-space optical communications at data rates up to gigabits/second as required for future deep-space optical communications.

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## Practical UAV Optical Sensor Bench With Minimal Adjustability

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A multiple-pass optical platform eliminates essentially all optical alignment degrees of freedom, save one. A four-pass absorption spectrometer architecture is made rigid by firmly mounting dielectric-coated mirror prisms with no alignment capability to the platform. The laser diode beam is collimated by a small, custom-developed lens, which has only a rotational degree of freedom along the standard optical “z” axis. This degree is itself eliminated by adhesive after laser collimation. Only one degree of freedom is preserved by allowing the laser diode chip and mount subassembly to move relative to the collimating lens

by using over-sized mounting holes. This allows full 360° motion of a few millimeters relative to the lens, which, due to the high numerical aperture of the lens, provides wide directional steering of the collimated laser beam.

Because the optical layout has been designed to provide proper mirror alignment for an orthonormal, paraxial laser beam, this degree of freedom is sufficient to insure perfect optical alignment once the orthonormal condition is satisfied. Further, the degree of freedom is enabled by using either simple loose metal screws in the over-sized laser mounting holes, plastic screws with low

tension, or a combination of the two. Once alignment is achieved, the screws are tightened sufficiently to insure ruggedness, or the plastic screws may be replaced, one by one, with metal screws. In either case, even the remaining degree of freedom is locked down after the final alignment. The final degree of freedom may be permanently, or quasi-permanently, locked by use of various adhesives on the screw head or threads.

*This work was done by Jeffrey Pilgrim and Paula Gonzales of Vista Photonics, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16536-1*