Sequence Detection for PPM Optical Communication With ISI

## Inter-symbol interference could be reduced.

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A method of sequence detection has been proposed to mitigate the effects of inter-slot interference and inter-symbol interference (both denoted "ISI") in the reception of M-ary pulse-position modulation (PPM) optical signals. The method would make it possible to reduce the error rate for a given slot duration, to use a shorter slot duration (and, hence, to communicate at a higher rate) without exceeding a given error rate, or to use a lower-bandwidth (and, hence, less-expensive) receiver to receive a signal of a given slot width without exceeding a given error rate.

In M-ary PPM, a symbol period is divided into M time slots, each of duration T_s, and a symbol consists of a binary sequence — ones and zeros — represented by pulses or the absence of pulses, respectively, in the time slots. At the transmitter, the bit stream is used to modulate a laser, the output of which is constant (either full power or zero power, representing 1 or 0, respectively) during each time slot. However, the signal becomes attenuated (signal photons are lost) in propagation from the transmitter to the receiver and noise enters at the receiver, complicating the problem of determining the timing of the symbol periods and slots and identifying the symbols.

The photodetector in a PPM receiver produces a pulse in response to each incident photon, so that, in effect, the receiver counts arriving signal photons. Because the duration of each pulse is finite, the response of the detector during a given time slot can include or consist of one or more tails of pulses from photons belonging to the preceding time slot (see figure). As a result, depending on the bit-to-symbol mapping of the PPM code in use, the receiver could interpret the current received symbol as other than the intended symbol. ISI is the tendency toward erroneous interpretation of this kind. The severity of ISI increases as T_s decreases. Hence, the pulse duration imposes a lower limit on the range of useable T_s values.

The present method of reducing ISI involves mathematical modeling of ISI, a novel bit-to-symbol mapping (that is, a novel PPM code), and an iterative demodulation-and-decoding scheme. The method can be implemented in a re-
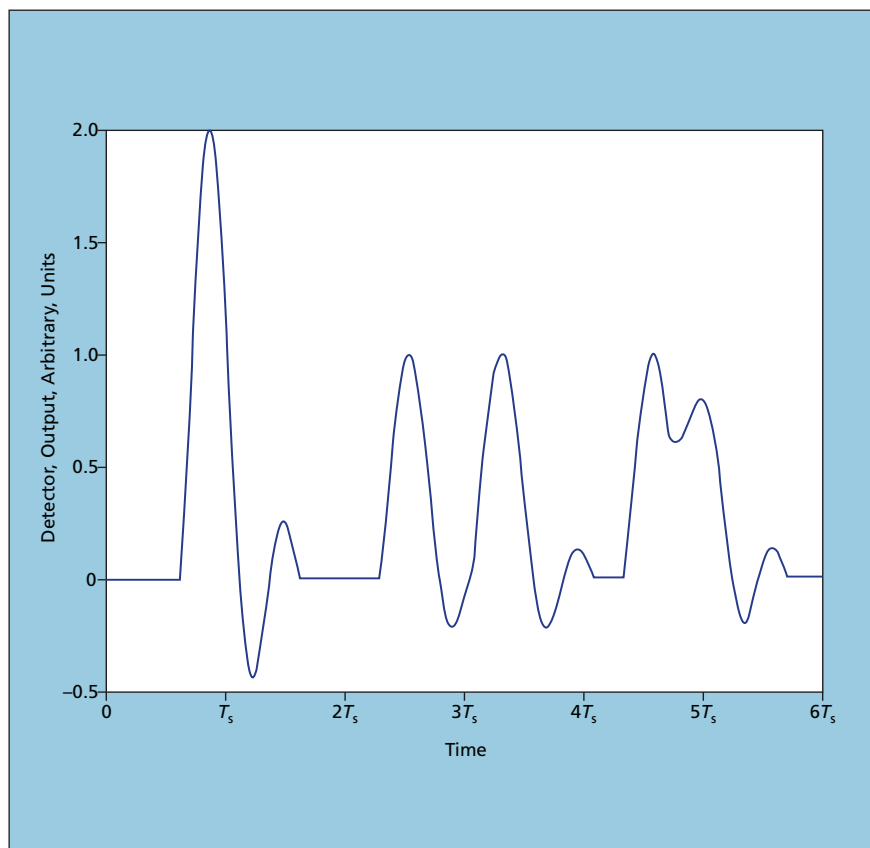
This **Example of a Detector Output** was simulated, using part of a sinc function with a main-lobe width of $T_s/2$ as a model of the detector response to a single photon. ISI occurs because a significant fraction of the response to a photon arriving in a given time slot occurs in the following time slot.

ceiver of relatively low complexity.

In the mathematical model, photons are assumed to arrive at randomly distributed instants during each time slot. The number of photons arriving during a time slot is assumed to be Poisson-distributed, with mean n_b in a noise-only ("0") slot or mean $n_s(1 - \beta/2) + n_b$ during a signal-plus-noise ("1") slot, where β is the average detector-output energy that appears in the adjacent time slots. The fraction β depends on the shape of the detector output pulse. The method includes dividing each T_s into a number (typically, 64) of sampling periods and summing the digitized detector-output samples from these periods to estimate the integral of the detector-output waveform. The sums thus computed are used, in conjunction with the mathematical model, to form likelihoods for the iterative demodulation-and-decoding scheme.

The novel bit-symbol mapping, denoted

anti-Gray, stands in contrast with two prior mappings, denoted natural and Gray, respectively. In a natural mapping, an input a (where a is an integer between 0 and $M - 1$) is mapped to a pulse in position a. In a Gray mapping, pairs of PPM symbols characterized by pulses in adjacent slots are mapped to input pairs with minimal Hamming distance (1). In an anti-Gray mapping, pairs of PPM symbols with pulses in adjacent slots are mapped to input pairs with maximal Hamming distance [$\log_2(M)$ or $\log_2(M) - 1$]. By means of computational simulations, it has been shown that an anti-Gray mapping reduces bit and word error rates, relative to those of a natural mapping, by amounts that correspond to a 0.25 dB increase in signal strength.