General purpose photon-counting minicomputer interface

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A general purpose photon-counting interface for use with a minicomputer (NOVA 3/12) is described. This device is capable of signal averaging and autocorrelating digitized data with sample time intervals of fixed or variable duration. Means are provided for experimental control and graphical display of results. Suggestions are given for minor modifications resulting in an even greater performance range.

INTRODUCTION

On-line digital recording of a time-dependent light intensity finds many applications in scientific research. Often in time-resolved light spectroscopy, a photomultiplier digitizes light intensity by detecting photons and yielding corresponding current pulses. It is desirable to electronically count the number of photoelectron pulses occurring in consecutive time increments and read this data into a laboratory minicomputer.

Data analysis for such experiments usually takes the form of a single scan transient recording,[1] signal averaging of repetitive signals, or autocorrelation.[2] In the past 10 to 15 years several devices designed for autocorrelation have been described.[3] Although the fastest autocorrelation devices are usually clipped,[4–6] Lempert and Wang[7] have recently described an unclipped autocorrelator operating up to 10 MHz. All of these devices are limited to equal length, equally spaced sampling intervals.

This paper describes a general purpose photon-counting minicomputer interface designed to allow a minicomputer to simultaneously control the counting and recording of the number of photons occurring during consecutive time intervals of presettable duration. The interface can be operated in a mode which varies the duration (but not the "spacing") of the user-defined sample time increment via an externally controlled input. Through the interface, the minicomputer can control the experimental apparatus via five control lines, and display a function (typically calculated from the incoming data) on an oscilloscope. Software has been developed to use the interface for transient recording, signal averaging, and autocorrelation. The interface is used with a NOVA 3/12 computer.

I. DESCRIPTION

As shown in Fig. 1, counting is performed in one of two modes. In the "internal" mode, light intensity is measured as the number of photomultiplier tube (PMT) amplifier/discriminator pulses[8] n_i occurring between times $i\Delta T$ and $(i+1)\Delta T$, for a sample time ΔT. ΔT is constant for all consecutive counting periods and is specified by the user to range from 1 μs to $2^{24}-1$ μs (~ 17 s). The n_i are counted as 16-bit binary words. In the "external" mode a voltage-to-frequency converter (VFC) generates pulses of frequency proportional to a reference signal. Light intensity is measured as the number of PMT pulses occurring between the first VFC pulse after time $i\Delta T$ and the next N VFC pulses, where N is user specified. The product (actual count time)·($\int$ reference signal) remains constant, thereby effectively normalizing the light intensity to the reference signal.[1] If N VFC pulses do not occur before time $(i+1)\Delta T$, a "ΔT error" has occurred and a hardware error flag is set.

Once the interface is started by software, the n_i are counted and stored in a 128-word first-in-first-out buffer. Data storage and retrieval from the buffer are transparent to each other and continue indefinitely unless the buffer fills, at which point data gathering stops. Thus, depending on the length of the sample time, data is supplied to the minicomputer as individual and consecutive words (long sample times) or 128-word nonconsecutive blocks (short sample times). Flags available to software indicate if a ΔT error has occurred (external mode), and if the buffer is empty, partly full, or full. In addition, software can request interrupts on the storage of a word or filling of the buffer.

While data is being collected and/or analyzed, software may output a 1024-point function for display on an oscilloscope or strip-chart recorder. The display is implemented by using two digital-to-analog converters (DAC). The DAC driving the x-axis is automatically incremented each time a new y-axis value is displayed. Software can also change the status of any one of five TTL control lines used to control experimental apparatus. With appropriate software, the interface can be used to record transients, signal average, or autocorrelate. The interface is treated as a peripheral in FORTRAN-callable assembly language subroutines.

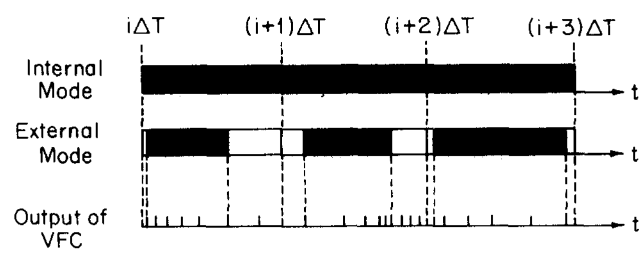

FIG. 1. External vs internal mode. The shaded area represents the actual time during which photons are counted. In the internal mode, the actual count time is equal to the sample time ΔT. In the external mode, the actual count times start at the beginning of the first VFC pulse, but the duration of counting is determined by the number of VFC pulses. In this example, the number of VFC pulses per count time is five.

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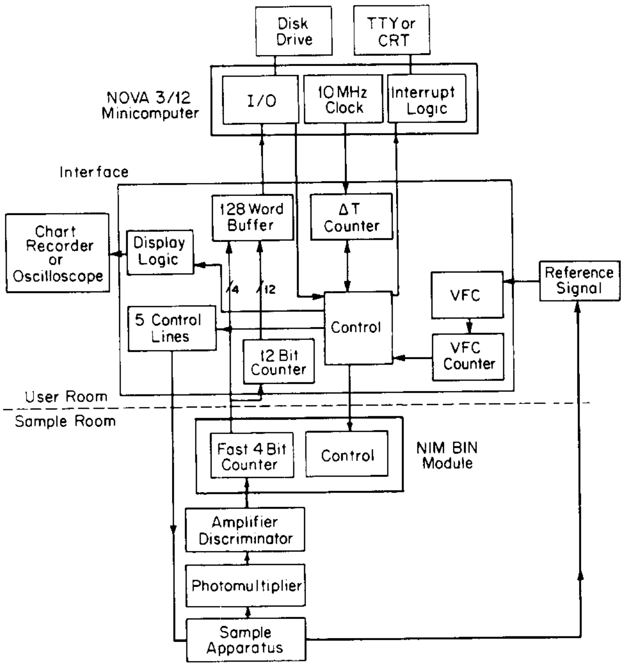

FIG. 2. Block diagram of the interface hardware. The interface to the minicomputer is split between a fast 4-bit counter next to the amplifier/discriminator and a board mounted in the computer backplane.

A block diagram of the interface is shown in Fig. 2. The four least-significant bits (LSB) of the counter, a combination of discrete components and Schottky TTL, are located in a single-width NIM bin module near the photomultiplier. The rest of the interface is located on one standard size NOVA board mounted in the NOVA 3/12 card rack. All hardware is either standard TTL or MOS. Remote location of the four LSB eliminates the need for a long high-frequency cable between the photomultiplier and the computer.[9]

II. RESULTS AND DISCUSSION

Correct operation of the interface has been verified by counting pulses of known frequency and phase with respect to the interface clock, and by photon counting actual samples of known time-averaged and autocorrelation functions. Figure 3 shows the autocorrelation function calculated when dim laser light passes through a revolving chopper wheel, combines with light from the tungsten lamp, and is incident on a photomultiplier. The photomultiplier signal passes through an amplifier/discriminator and then to the NOVA 3/12 interface. The wheel rotates at 1800 rpm and has two opposite quarters open, producing a 60-Hz, 50% duty cycle square wave. The intensity of the tungsten lamp is varied to adjust the percent of the total light that is fluctuating. As shown, the autocorrelation function resembles a triangular wave (as it should) and has the correct period of 16 2/3 ms. The $t \to 0$ value is near that expected for a perfect square wave (f^2) where f is the fraction of the light fluctuation, and changes when f is experimentally varied. The actual value at time zero includes the autocorrelation of shot noise, and is equal to the reciprocal of the average number of counts per sample time.

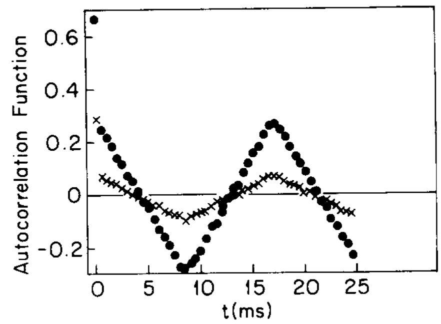

FIG. 3. Autocorrelation of square wave. Above are autocorrelation functions of fluctuations in light intensity measured for a signal composed of a constant intensity plus 54% (●) or 28% (×) square wave. The period of the autocorrelation function is the period of the square wave, the value as $t \to 0$ is slightly less than that expected for an ideal square wave (fraction of fluctuation squared), and the $t = 0$ value is approximately equal to the reciprocal of the number of photoelectron counts per sample time.

This general purpose photon-counting interface described here has sufficient flexibility to signal average and autocorrelate using fixed or variable-counting intervals. The use of the four LSB in the NIM bin permits one or more sets of experimental apparatus to be remotely located from the computer. Data may be displayed on an oscilloscope in real time, thus aiding in early detection of possible sample disarray. The interface has been used as an autocorrelator in a study of immunoglobulin surface binding kinetics.[10]

Although the authors have not done so, it would be possible to replace the VFC with a start and stop pulse, thus counting all events between user-defined times. In addition, with minor modification to the interface, it would be possible to use it with any computer possessing a general purpose parallel input/output interface.

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