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Improved electronic readout system for an imaging photon detector

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Abstract

Photek manufacture microchannel-plate based Imaging Photon Detectors, which are able to detect and image single photon events enabling high resolution in both event time and position. We have developed a new system of IPD electronics that has time detection jitter of 1.5ns and a spread of 4ns across a pulse height distribution ratio of 10:1. The rise time of the preamplifiers is in the region of 8ns. The noise in the electronics sets a limit on the position resolution that is smaller than the microchannel-plate pore size, typically 10μm. We have also included a discrimination system to reject overlapping events and hence greatly reduce image distortion, and the electronics can handle events of nearly $10^6 s^{-1}$. Further improvements include a sine wave driven high voltage unit with a high signal protection system, and a greatly reduced unit size by moving to surface mount technology.

Keywords: Microchannel Plate; photon; imaging; detector

1. Introduction

Imaging photon detectors (IPD) manufactured by Photek offer photon counting with imaging capabilities giving a position resolution to rival that of an intensified CCD system but can also offer high time resolution of the photon events. Imaging is made possible through the use of microchannel plates (MCP) as the electron amplification method.

Figure 1 shows a general layout of an IPD tube. Photons incident on the photocathode are converted to photoelectrons, which are accelerated and amplified through the microchannel plate stack by a high voltage field. External electrodes detect the electron charge landing on the anode. The anode may be a resistive layer of the pincushion design that uses a strip resistance around the edge to simulate an

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infinitely sized resistive sheet [1], or a charge division pattern such as a wedge and strip [2]. The relative signal strength at each electrode indicates the position of the event.

We have developed new electronics to improve the various key parameters of the system; position resolution, time resolution, response time, count rate ability, image quality and overall camera size.

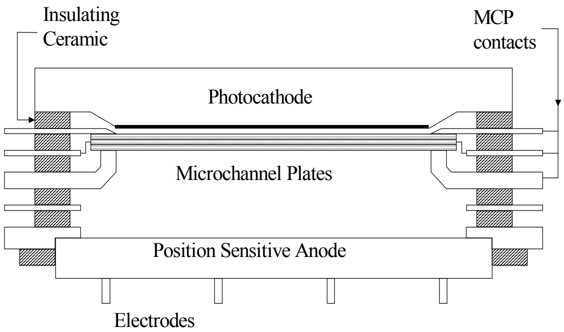

Figure 1 Schematic diagram of a Photek IPD.

2. Electronics Design

2.1. Analogue electronics

Each electrode is connected to a pre-amplifier electronics channel that needs to amplify the signal and alter the event pulse to one that can be most efficiently read by an analogue to digital converter (ADC). A double-JFET front-end amplifier for the pre-amplifiers increased the gain and therefore the response time (or rise time) to 8ns. A carefully balanced impedance stage with a bootstrapped output is then passed to a pulse-shaping filter.

We have developed a double 2nd order unipolar pseudo-gaussian pulse-shaping filter (as described by Mosher [3]) because it gave the smoothest pulse for ADC conversion while maintaining a short pulse width, in this case 1μs. A unipolar pulse requires a baseline restorer because of dc shifts to the baseline, and we have developed an active baseline restorer that gives a variation in linearity of less than 0.17%. This forms the final part of the analogue pre-amplifier before the signal is passed to the ADCs.

2.2. Timing electronics

The time of a photon event is detected by using a constant fraction discriminator (CFD). Figure 2 shows the pulses in the CFD where the signal pulse is

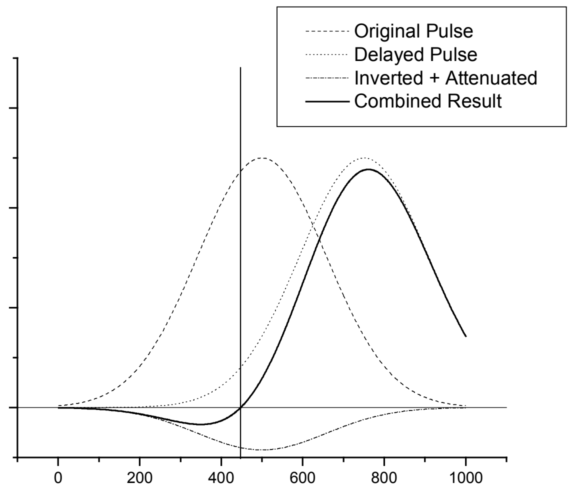

Figure 2 Constant Fraction Timer.

split, one being inverted and attenuated while the other is delayed. The signals are then recombined and the result has a zero-crossing point that is reasonably independent of the amplitude giving an accurate time tag for the event [4].

Figure 3 shows the drift of the timing signal compared to the amplitude of the pulse, as it would appear on the pulse height distribution (PHD), giving a 4ns drift over the useful area of 25 to 250 (the PHD is scaled from 0 to 255). The jitter at a single point on the PHD graph is about 1.5ns.

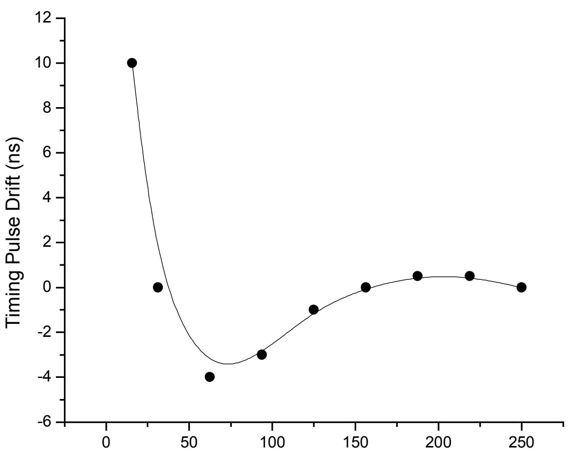

Figure 3 Drift of timing signal with pulse height.

2.3. Event detection

The timing signal will be used to trigger the ADCs in the digital section. This allows us to improve the image quality by preventing pulses from combining and producing a false event position, i.e. if two events occurred within 1µs of each other their respective anode signals would combine on the analogue preamplifier channels to produce a false position reading and therefore degrade the image quality.

We have developed a discriminating logic sequence that does not allow two timing signals to occur within 1µs of each other, therefore overlapping events are effectively rejected and ignored by the electronics. Statistically the number of lost events would only become significant at a count rate above $10^5 s^{-1}$, below the normal operating boundaries of an IPD.

2.4. Digital electronics

The pseudo-gaussian anode pulses from the preamplifiers are passed to 12-bit ADCs with an external trigger provided by the timing signal. The digital values from the ADCs are multiplexed along with the time value of the event (taken from a fixed start point) and some further status bits and sent down a serial link to a PCI card in a computer. A serial link is used for high-speed communication and minimal wiring. The Photek software will then calculate the position of the event by using the relevant algorithm (this depends on the type of anode used).

3. Position Resolution

The 12-bit ADCs have a scale of 0 to 4095. When an external test pulse was injected into the analogue channels and calibrated for 40% of the full scale of the ADCs (1638) the electronic noise produces a standard deviation (σ) between 0.5 and 0.6 LSB.

3.1. Eror Progression

To calculate the limit to the position resolution from theses values we can use error progression theory along with the position algorithm for the various anodes. For the case of the resistive anode algorithm the resulting standard deviation in the position of an event for a 25mm diameter tube would be 4µm. This corresponds to a FWHM of a point-spread function of 9.4µm. For a larger detector this theoretical value would simply be scaled up accordingly.

3.2. Pixel Expansion

A more direct method of measuring the position resolution limit in the electronics is by pixel expansion. The image produced by the Photek software is a 512 × 512 pixel array. In a 25mm diameter tube one pixel would therefore be approximately 71µm square (the working area of the anode in this tube is not exactly 25mm diameter). Clearly the electronics limit would not be seen by this image but the Photek software allows us to expand the pixels to a larger scale.

By expanding 1 of the old pixels to a grid of 12 × 12 new pixels the FWHM of the point-spread function from an externally injected pulse was 8µm. This shows reasonable agreement with the error progression method but the slight improvement is attributed to correlation between error sources that was not taken into account in the error progression calculations.

3.3. Anode noise

Charge division anodes have no inherent resistance and therefore do not produce electronic noise by themselves. However the resistive anode is effectively a resistive contact to signal ground and as such is a source of Johnson noise [5]. The construction of the anode and in particular the compensating strip around the edge is the dominating noise source in IPDs that use such anodes.

A resistive anode was attached to the preamplifier channels and the pixel expansion method to measure the point-spread function from an external test pulse was repeated. The resulting FWHM for a 25mm diameter IPD tube was 15.1µm, nearly double that without the anode attached. This clearly shows the advantage of charge division anodes.

3.4. Resolution against pulse height

It should be noted that these experiments were done with an external test pulse calibrated to 40% of the ADC full scale. Varying the height of this pulse has a dramatic effect on the FWHM as shown on figure 4.

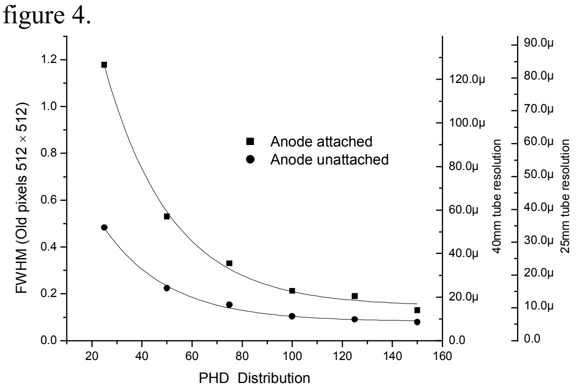

Figure 4 Variation of the electronics limited FWHM with pulse height

However the lower end of the PHD is rarely used as it contains the signal produced by various noise sources within the tube (e.g. cathode noise) and can easily be discriminated out by the Photek software. For a given PHD from an IPD tube we can use a simple calculation along with figure 4 to give the theoretical position resolution limit. Typically this gives a point-spread function with a FWHM between 25µm and 30µm.

4. High voltage unit

For the new IPD system we have developed a sine wave driven high voltage unit that avoids the electronic noise associated with comparable switching high voltage supplies. The new unit also contains an anode current monitor that automatically turns off the cathode if the signal level reaches a pre-set count rate, therefore protecting the IPD tube.

In conclusion we have developed a new system of IPD electronics that can produce a time signal for a photon event accurate to 4ns and a position resolution for a resistive anode below 30µm FWHM and approaching MCP pore size (typically 10µm) for a charge division anode. We have developed an event discriminator to improve image quality and have developed these features in surface mount technology to reduce the size of the IPD camera.

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