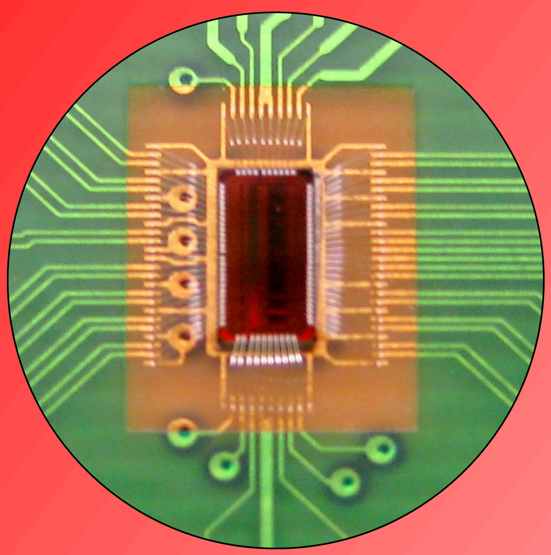
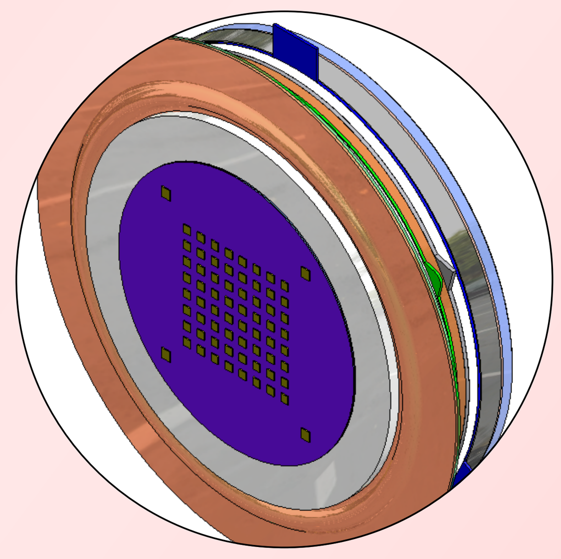
Detector and Electronics R&D for picosecond resolution, single photon detection and imaging

T.M. Conneely, J. Lapington
University of Leicester
J.S. Milnes
Photek LTD.



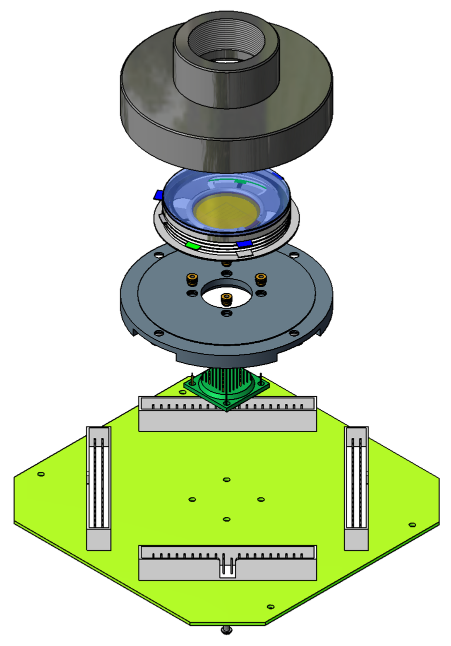


Abstract

The University of Leicester & Photek are pursuing a number of R&D projects for detection of single photon events with time resolution of the order of 25 ps. Sources of detector jitter are discussed, with initial results from the calibration of the HiContent detector, an 8×8 multi-anode MCP detector using the NINO FEA and HPTDC for readout. These results show a RMS timing jitter of 100-150 ps with sub-optimal experimental setup.

HiContent Prototype Specifications

- 8×8 anode multilayer ceramic
- 16×16 mm active area, with 0.8 mm square anode pads
- Two chevron-stack 3 μm MCPs offer high gain of ~1×10^6 and fast detector response (80-90 ps rise time)
- 8 NINO chips, with eight channels each, closely coupled to detector
- Headers for connecting detector to Caen VME HPTDC module



Readout Electronics

- NINO ASIC - an 8 channel differential amplifier/discriminator, using a time over threshold technique. Excellent time resolution of up to ~10 ps RMS jitter on the leading edge, with LVDS outputs common-mode noise rejection.
- High Performance Time-to-Digital Convertor - A programmable TDC, with a ultrahigh resolution mode (allowing 25 ps LSB resolution on 8 channels).

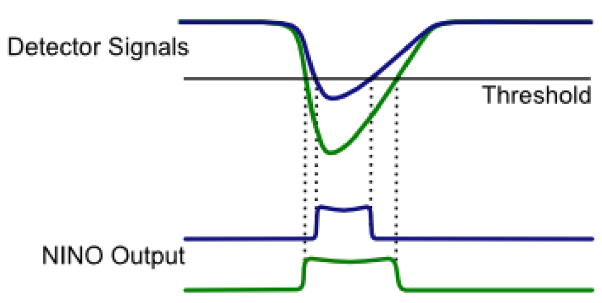


***Figure 1** - Schematic illustration of the NINO output from two signals*

Timewalk Calibration

The NINO ASIC uses a time-over-threshold technique to measure the detector signal, as shown in Figure 1, this produces a LVDS logic output with width proportional to the collected charge. A side effect of this technique is a "timewalk" of the leading edge due to variation of the input signal's amplitude, this affect must be calibrated for to achieve sub-100 ps time resolution. As an MCP detector produces a broad pulse height distribution (PHD) the detector output was used for the calibration procedure.

To perform the calibration the detector was illuminated with a pulsed laser, which provides an absolute reference time for the timewalk calibration. Hence, using the HPTDC VME module, manufactured by CAEN, to measure the time of the NINO output's leading edge and the pulse width a histogram can be built up. Figure 3 show's calibration data for a single channel (the second peak is due to optical reflections). The histogrammed data was used to generate a look up table for the leading edge timewalk correction, by fitting a spline curve to the maximums. Using this look up table the leading edge time of the NINO outputs can then be corrected, and the detector system jitter measured.

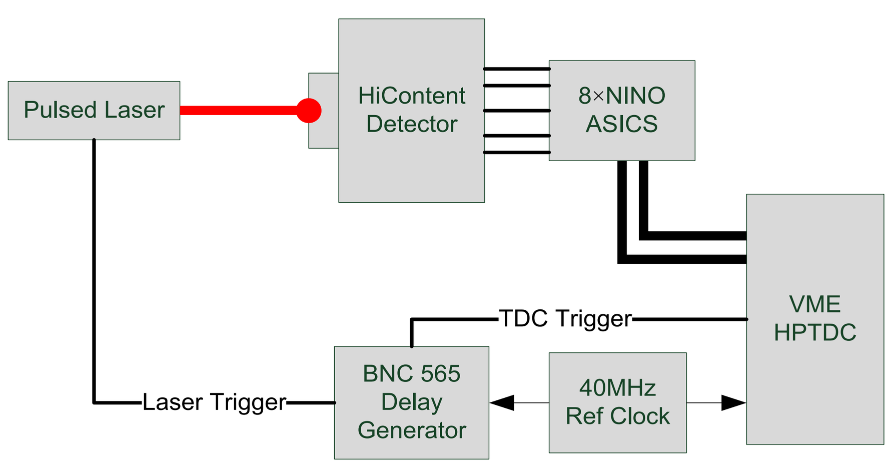


***Figure 2** - Experimental schematic*

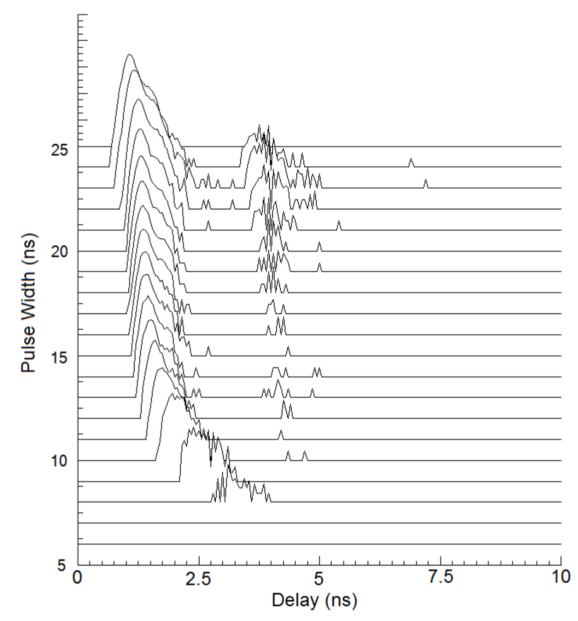


***Figure 3** - Calibration data, a fit to maximum of peaks used for pulsewidth/ risetime calibration, width is the jitter*

Detector Jitter Measurement

Figure 4 shows the post-calibration NINO rise time data for a single channel, the distribution has the form of an asymmetrical gaussian, with a slight tail of delayed events. The distribution's shape agrees well with previous measurements of 3 μm MCP-PMT's single photon transit time spread (TTS), performed with an oscilloscope although significantly broadened. The plot shows a 2-gaussian fit of the data, which closely matches the distributions shape (A_1=8618, t_1=1696 ps, σ_1=107 ps, A_2=1721, t_2=1842 ps, σ_1=255 ps).

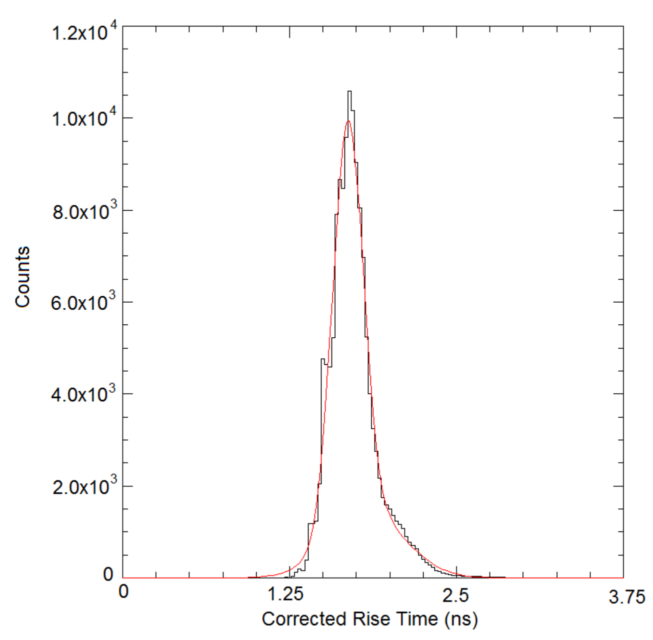


***Figure 4** - Corrected rise time data, with two Gaussians fitted, σ_1 =107 ps for the main Gaussian peak*

However, the distribution includes contributions from two measurable sources, the temporal pulse width of the laser of 40 ps and the delay generator's output jitter which was measured to be ~65 ps. Subtracting the non-detector jitter contributions in quadrature:

$$\sigma = \sqrt{107^2 - 40^2 - 65^2}$$
$$\sigma = 75 \text{ ps}$$

However, this figure does not take into account noise pickup, which is an acute problem for the current experimental setup. One noise problem is related to reading out the VME HPTDC module using USB, which injects noise into the NINO inputs. Also, the current experimental setup is not ideal, with the noise levels, measured to be 10-100 mV in amplitude with an oscilloscope, this being heavily dependent upon the positioning of cabling and equipment near the detector. Hence, future work will focus on eliminating noise sources, and integrating the readout electronics/detector into a single package.

Future Plans

We are currently developing our own modular HPTDC device,

- Two HPTDC cards giving 64 channels at 100 ps or 16 channels at 25 ps
- On-board FPGA for control and data processing
- USB readout and control
- A pluggable architecture, allowing multiple HPTDC cards (maximum of 16 HPTDCs)

The design will become a general purpose TDC box suitable for "benchtop" experiments, with plans to add higher bandwidth interfaces for installation in more advanced detector systems e.g. a DIRC.

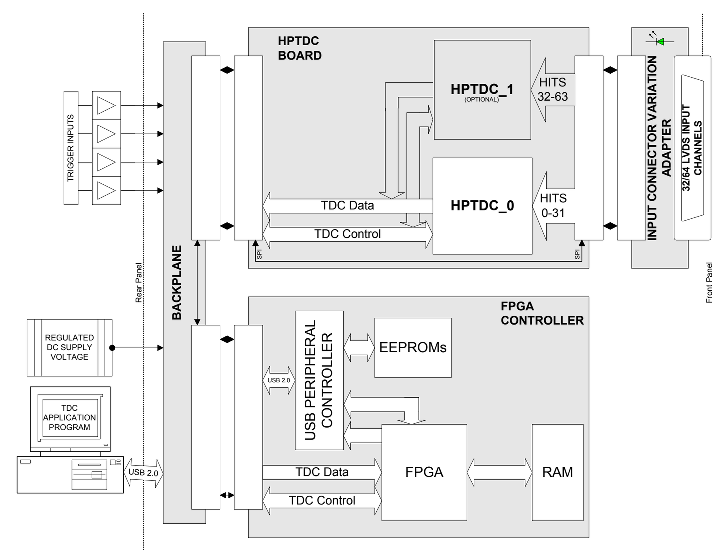


***Figure 5** - HPTDC architecture*

The next phase of the HiContent project is to build a larger detector with a significantly higher pixel density, this will be called IRPICS. We are also utilising the NINO/ HPTDC for a new resistive sea anode design, based on a capacitive matrix which allows position sensitivity (using a centre of gravity technique), high single photon time resolution of around 25 ps and a high event rate.

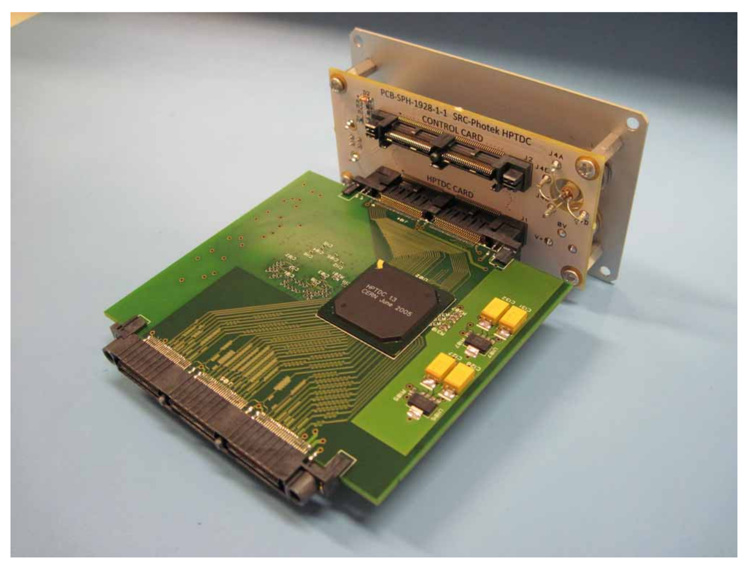


***Figure 6** - HPTDC prototype, showing 64 channel HPTDC board and backplane*

Summary

The HiContent detector is an 8×8 multi-anode detector, which coupled with the NINO and HPTDC, developed at CERN, provides sub-100 ps timing resolution. Early measurements show a promising result of 75 ps RMS jitter, with scope for a great deal improvement by integrating the detector system.

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