Operation of Microchannel Plate PMTs with TOFPET multichannel timing electronics

Steven A Leach[a,*], Jon S Lapington[a], James S Milnes[b], Tom Conneely[b], Ricardo Bugalho[c], Stefaan Tavernier[c,d]

[a] *Space Research Centre, University of Leicester, UK*
[b] *Photek Ltd, UK*
[c] *PETsys Electronics, SA, Portugal*
[d] *Vrije Universiteit Brussel, Belgium*

Abstract

We describe an experimental programme to evaluate TOFPET multichannel timing electronics using microchannel plate PMTs in single photon counting mode. Time resolution measurements were made using: i) the on-board electronic stim signal; ii) a Photek PMT210 high speed single anode MCP photomultiplier detector, and; iii) imaging with a PMT240MA multi-anode MCP detector using a pixelated multi-layer ceramic readout.

Experimental measurements using an electronic stim with the ASIC electronics gave a time resolution of 43 ps rms. Detector timing of the PMT210 detector was evaluated using a 40 ps wide pulsed laser with amplitude walk correction using the time over threshold capability of the TOFPET electronics. Single photon timing resolution of better than 100 ps rms was demonstrated.

Furthermore, 256 discrete pixel imaging has been demonstrated by coupling a multi-anode pixelated MCP detector to the TOFPET system.

Keywords: TOFPET, ASIC, Front-End Electronics, FEE, Time of flight, MCP, Microchannel plate, PMT, Photomultiplier tube

1. Introduction

The TOFPET (Time-of-Flight Positron Emission Tomography) ASIC (first generation design) is a 64 channel mixed-mode chip, developed by PETsys Electronics, SA, Portugal in 130 nm CMOS technology and described as having 25 picosecond (ps) intrinsic resolution, low power consumption and featuring fully digital output [1]. The readout employs a dual-threshold technique: the event pulse is branched into time and energy channels each with discriminators with independently settable thresholds. Dual time-to-digital converters (TDC) time stamp the fast rising edge of the time signal and the falling edge of the energy signal providing a time-over-threshold (ToT) measurement, the dual-threshold technique also provides improved dark count rejection. TDC data is extracted by a global controller and output using an LVDS digital interface. Data acquisition is performed by a host PC and the data framesets comprise individual event data containing event time, channel ID, time-over-threshold (ToT) and validity.

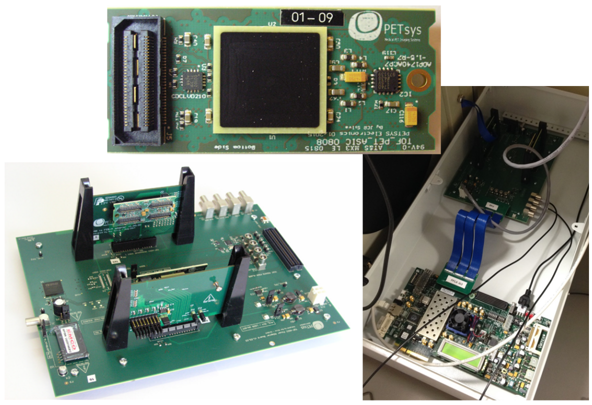

Figure 1: PETsys TOF ASIC evaluation kit v4 provides 256 independent channels. The TOFPET ASIC board (top), the Power Adapter Board (PAB) (left) and the ML605 FPGA evaluation board with PAB enclosed as a demonstration unit.

The PETsys TOF ASIC evaluation kit comprises 4 TOFPET ASIC chips, adapter and power boards, and a Xilinx FPGA development board providing clocks, control and data acquisition functions [2]. TOFPET is optimised for SiPM ar-

*Corresponding author
Email address: drleach@physicsresearch.co.uk (Steven A Leach)

ray applications but this study investigated operation with microchannel plate photomultipliers (MCP-PMT). The evaluation kit v4 shown in figure 1 comprises 256 independent channels. For these measurements, impedance optimised header boards (SMA-FEB) were designed to interface between the detectors and the ASIC input channels.

2. TOFPET Performance with Internal Test Pulse

An internal FPGA-generated test pulse was fed to a charge injection circuit which directly triggered the ASIC front-end for signal calibration (see figure 2 for ToT calibration and event arrival time spread). A time resolution of σ=43 ps was measured after applying amplitude walk correction (AWC) obtained from the ToT data.

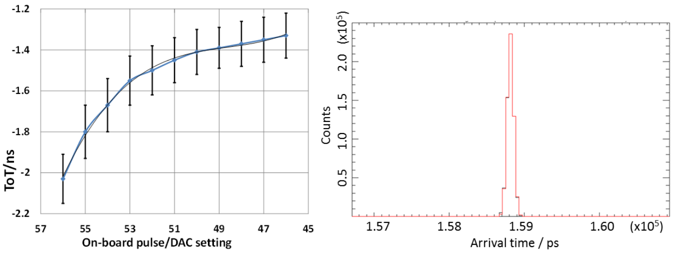

Figure 2: Calibration response to the internal test pulse over a set of amplitudes (left). The test signal is DAC-controlled with an inverted scale (63 low, 0 high). The ToT conversion includes negative values at this signal level due to a fixed 8 ns delay in rising edge time stamp. An arrival time histogram (shown right) for the internal test pulse has a measured resolution of σ=43 ps after applying AWC obtained from the ToT data.

3. Performance with a MCP-PMT Detector

The SMA-FEB adapter board was mounted inside a dark box and coupled with the signal output from a single anode PMT210 connected to an individual ASIC channel (see figure 3). The FPGA-generated on-board test pulse triggered a 405 nm (40 ps width) pulsed laser producing photon pulses synchronous with the TDC clock. The detector was illuminated in single photon mode (via ND 5.5 filter) and ToT data analysed to estimate the gain of $\sim$ 8.2$\times$ 10^5 electrons. Contour plots of ToT versus time data are shown in figure 4 before and after AWC which employed a simple linear fit. Figure 5 is a histogram of the corrected arrival time representing a time resolution of σ=96 ps.

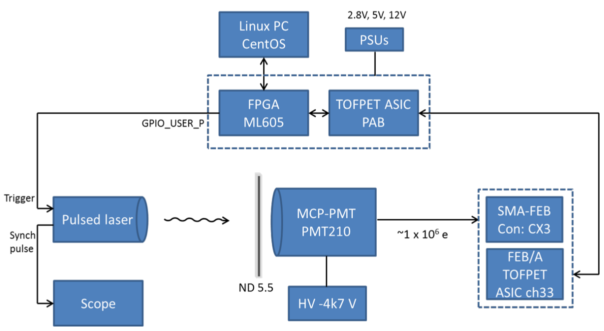

Figure 3: Schematic diagram of the single anode MCP-PMT test configuration for evaluating system performance.

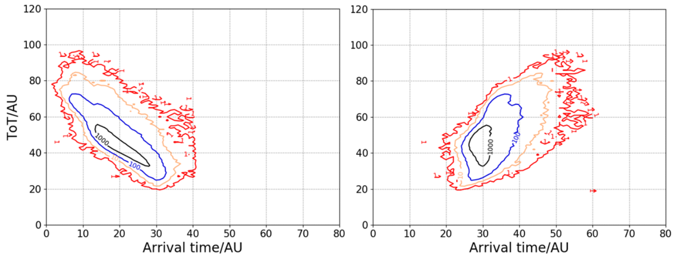

Figure 4: Logarithmic contour plots of ToT versus arrival time for the MCP-PMT in single photon mode at a gain $\sim$ 8.2$\times$ 10^5 electrons revealing amplitude walk (left) and after AWC (right).

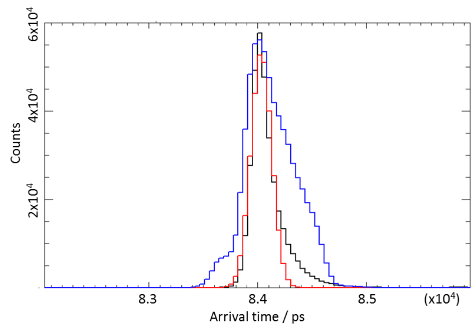

Figure 5: Histogram of the event arrival time after AWC (black) and fitted with a Gaussian (red). AWC improves time resolution from σ=225 ps (blue, normalised) to σ=96 ps (black). In future analysis an empirical look up table implemented per channel will be used to accommodate any non-linear response.

4. Multi-anode 256 pixel imaging

Figure 6 (right) shows the image of a focused laser illuminating a PMT240MA multi-anode MCP-PMT with 16 $\times$ 16 pixellation. The pixelated readout is electrically coupled via an anisotropic conductive film and impedance matched header PCB to four TOFPET ASICs (figure 6 left).

Further work has begun to test and characterise the latest TOFPET2 ASICs using an MCP-PMT detector configuration.

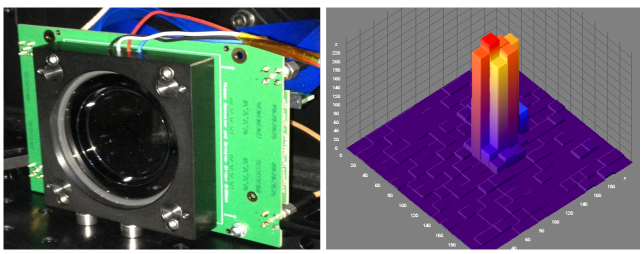

Figure 6: A multi-anode MCP-PMT (PMT240MA) with pixelated readout and impedance matched header PCB (left) and resulting image of a laser spot (right).

[1] R. Bugalho et al., "Design and performance of an ASIC for TOF applications," 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC), Seoul, 2013, pp. 1-4.
[2] PETsys Electronics, Mar 2016. PETsys TOF ASIC Evaluation Kit_v4 - Hardware User Guide. 1.0 edn. PETsys