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Photomultiplier pulse timing using flash analog to digital converters*

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Abstract

A method for determining the arrival time of a photomultiplier pulse using a flash analog to digital converter is discussed. The method duplicates the function of a constant fraction discriminator and a time to digital converter. Measurements indicate a time resolution of 157 *picoseconds* can be achieved using a flash ADC with a 4 *nanosecond* sampling period and an 8 bit sample depth.

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1 Introduction

Photomultiplier tubes (PMT) are used in many applications, in particular, high energy and nuclear physics experiments. In these applications, the PMT produces a pulse with properties related to some physical process being measured. Consider electromagnetic calorimetry, for example. A typical calorimeter uses PMTs to determine the amount of light produced by a radiator when struck by a high energy photon or electron. The amount of light so produced is proportional to the energy of the incident particle.

Nearly all experiments to date have used integrating analog to digital converters (ADCs) to measure the amount of light produced. These devices require a gate during which the current from the PMT is integrated. All time information as to the arrival of the incident particle is lost by this method, only the time of the gate (perhaps) is preserved.

This arrival time information is valuable in high rate experiments both current [1] and proposed [2] for the near future. It can be used to eliminate "pile up", that is, to remove events where two or more interactions occur during the integration time of the ADCs. This arrival time could also be used to determine time differences in the experiment, for example, in a time of flight particle identification system. This time can be determined by conventional time to digital converters (TDCs) but this requires splitting the analog signal from the calorimeter PMT into two paths, one to the ADC, another to a discriminator and TDC. (see, for example, [3]) The additional cables and electronics leads to considerable expense and degradation of signal.

In this paper we discuss a method to determine the time of certain "features" of phototube pulses using only a relatively low frequency flash ADC (FADC). A FADC digitizes continuously and preserves pulse amplitude and *shape* information. This shape information can be used to determine the arrival time of selected features of the pulse. [4] The algorithm deduced to determine the time of these features was tested against a large number of PMT pulses digitized at 2.5 GHz by a Tektronix model TDS 7104 digital oscilloscope.

2 Characterization of pulses

To determine the suitability of FADCs as time measurement devices, a large sample of PMT pulses with known feature times was required. We have used a digital oscilloscope and a PMT suitable[5] for electromagnetic calorimetry, the Russian made FEU-84-3. The digital data so obtained could be transformed to simulate the response of a FADC and fitted to give the required feature times. The operational details of the procedure are given below.

A Laser photonics model LN300C nitrogen laser illuminated a small piece of scintillator. The light produced was propagated via optical fiber into a darkened cylinder containing a FEU-84-3 PMT operating at 1800 volts. (1900 V is the recommended maximum for this tube) By changing the distance from the end of the fiber to the PMT photocathode, a variety of pulse amplitudes could be obtained. Another PMT, an RCA 8575, illuminated by another fiber driven by the same scintillator, produced a pulse used to trigger the oscilloscope. The digitized pulses from the FEU-84-3 were stored for later analysis.

This procedure produced a “library” of 857 digitized pulses with peak amplitudes between -0.3 and -1.1 volts. Each pulse was sampled 500 times at intervals of 400 *picoseconds* and digitized to 8 bits. Each sample had a time reckoned relative to the trigger and this time was also recorded. These sampled pulses are the source of data for this investigation. The interesting samples of typical pulse are shown in figure 1a.

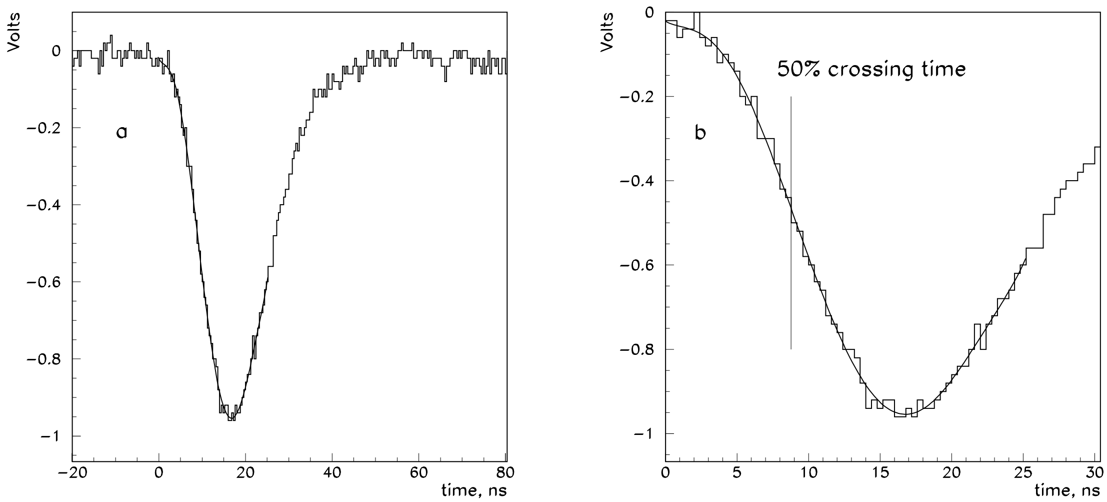

Figure 1: A) The relevant samples of a typical pulse obtained with the oscilloscope are shown. The sampling period is 400 *picoseconds*. B) The result of fitting the samples to a polynomial and the result obtained from that polynomial for the 50% of peak crossing time.

To determine the relevant times from these measurements, the samples were fitted to a 9th degree polynomial. This polynomial was used to determine the time where the pulse achieved 50% of its peak value (on the leading edge) and the location in time of the peak of the pulse. The part of a typical pulse used for this procedure, along with the fitted polynomial is shown in figure 1b. These feature times were determined and recorded for all the pulses in the library.

3 Simulation and transformation of pulses

The digitized pulses were transformed into the simulated response of a FADC. Averaging over time samples simulates the sampling period of a FADC, for example, averaging over intervals of 10 samples, simulates a 250 MHz (4 *ns* period) FADC. Digitization effects are simulated by taking the average voltage obtained by this method and converting it to an integer according to some mapping. Equation 1 gives this mapping. Shown in figure 2a is a typical pulse mapped into a simulated FADC response.

$$[0; V_{min}] \rightarrow [0; 2^n - 1] \tag{1}$$

In equation 1 V_{min} is the voltage where the FADC would register full scale and n is the number of bits of the digitizer. For this study, three values of V_{min} were used, -1.25, -3.0 and -5.0 V. 8 and 10 were used for n.

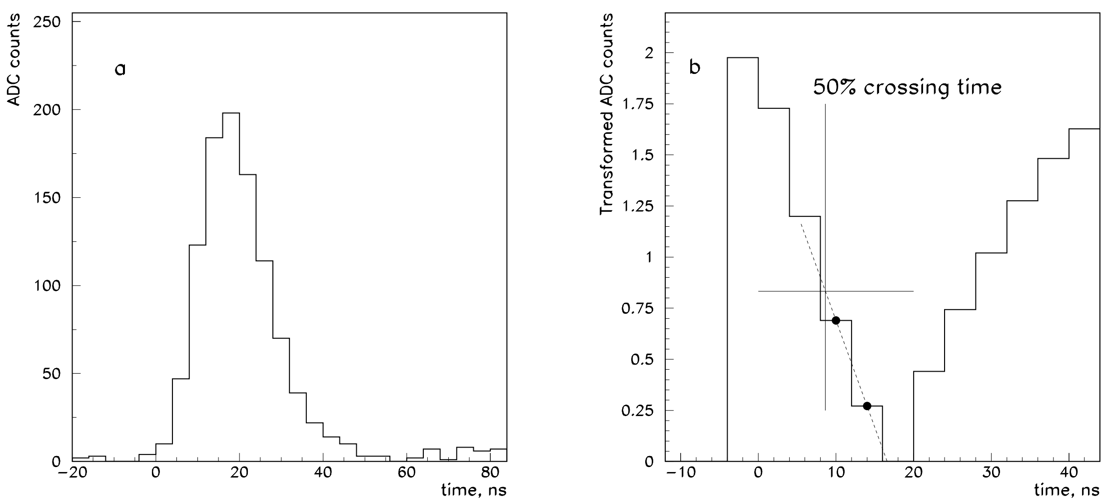

Figure 2: A) The simulated response of an 8-bit, 250 MHz FADC generated from a typical pulse by the method described in the text. B) The FADC response transformed by eqn. 2 and an illustration of the method used to find the 50% crossing time.

Examination of the pulses in the pulse library led to the observation that the leading edges of the pulses were nearly Gaussian in shape. This suggests a transformation that turns a Gaussian edge into a straight line,

$$S'_i = \sqrt{-\ln\left(\frac{S_i}{S_p}\right)} \tag{2}$$

where S_p is the value of the peak sample, S_i are other samples and S'_i are the transformed samples. Note that S_p is transformed into zero. Shown in figure 2b is a typical pulse after this transformation. Given any two transformed samples, the slope and intercept of a straight line connecting them can be calculated. This line, in turn, determines where the pulse achieved any particular fraction of its peak value. Let m and b denote the slope and intercept then

$$mT_p + b = 0 \tag{3}$$

gives the time of the peak and

$$mT_{50} + b = \sqrt{-\ln\left(\frac{1}{2}\right)} \tag{4}$$

gives the time of the 50% crossing.

Finally, an amplitude slewing correction was found to be required. This correction was taken as linear and is given by eqn. 5.

$$t' = t + qV_p + d \tag{5}$$

where q and d are determined from the data.

V_{min}	8-bit, 250 MHz 50% time	8-bit, 250 MHz peak time	10-bit, 250 MHz 50% time	10-bit, 250 MHz peak time
-1.25	157 ± 6	340 ± 12	161 ± 6	340 ± 12
-3.0	176 ± 7	339 ± 12	164 ± 6	340 ± 12
-5.0	228 ± 9	331 ± 12	162 ± 6	339 ± 12

Table 1: The resolution obtained (*picoseconds*) for the two features considered and various values of full scale voltage for the FADC.

Implementation of this algorithm requires the choice of two particular samples. For a 250 MHz sampling frequency and this particular PMT, it was found that the two samples immediately preceding the peak sample gave the best measure of the 50% crossing time. In figure 2b a transformed pulse is shown as is the resulting straight line that estimates the 50% crossing time. The peak time was best located using the peak sample and the sample preceding it.

4 Results

The distribution of the difference between the time determined by the detailed fitting (using the polynomial) and the method discussed above was histogrammed and fitted to a Gaussian to determine how accurately the feature times could be determined. The result for the 50% crossing time with $V_{min} = -1.25V$ is shown in figure 3. The standard deviation of the fitted Gaussian obtained was 157 ± 6 *picoseconds*. Results for other values of V_{min} and for the determination of peak time are given in table 1

As can be seen from the table, when an 8-bit sample depth is used, the resolution of the 50% crossing time degrades as V_{min} becomes larger in absolute value. This is can be understood by noting that the algorithm depends on differences between samples (to determine a slope) and that truncation errors become more significant in the evaluation of these differences as the sample values approach zero. This conclusion is supported by the result of a simulation of a 10-bit FADC.

5 Discussion

A simple algorithm for determining the arrival time of a PMT pulse has been described. This technique could be used, for example, to reduce the amount of data that must be recorded to characterize a PMT pulse. The pulse data could be reduced to an arrival time and some measure of amplitude (for example the pulse integral) and these quantities could be stored rather than the pulse samples.

The algorithm is also ideally suited to signal processing applications. Consider a signal consisting of a stream of FADC samples. All that is required to evaluate the arrival time is values for the current sample and two samples preceding it. Once a local peak was identified (a simple problem) the arrival time of the event causing the peak would be known.

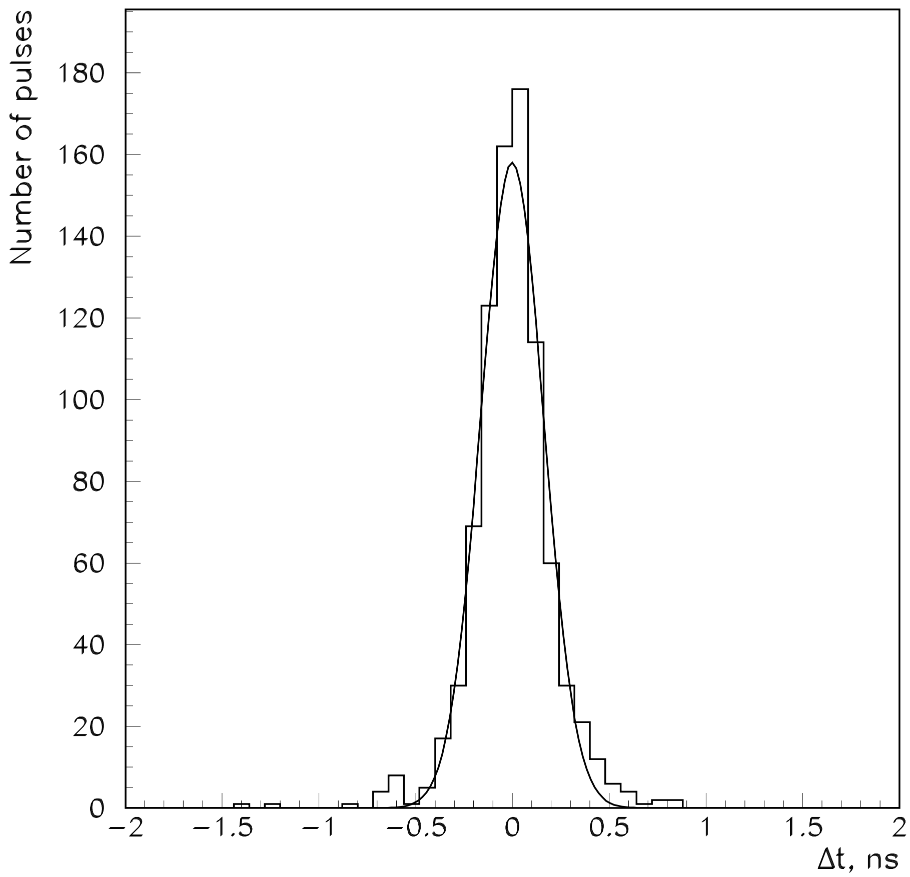

Figure 3: The difference between the time of the 50% crossing as determined by detailed fitting and as determined by the algorithm discussed in the text. This crossing time is reproduced with a resolution of 157 *picoseconds*, approximately 1/25 of the FADC sampling period.

Finally, the algorithm is sufficiently flexible to allow different pulse features to be used. For example, precision timing of phototube pulses typically relies on the use of the constant fraction discriminator. As illustrated above, the algorithm can determine the location in time where the pulse achieves 50% of its peak value with a resolution smaller than the sampling period. Should some other feature of the phototube pulse be found to preserve the timing information of the physical process causing the pulse, this algorithm can be adapted to extract that time.

References

[1] N. Cavallo Nucl. Phys. B (proc. Suppl.) 78 (1999) 64-71

[2] http://dustbunny.physics.indiana.edu/HallD/

[3] R.-D. Appuhn *et al.* Nucl. Instr. and Meth. A 426 (1999) 518-537.

[4] H. Bergauer *et al.* Nucl. Instr. and Meth. A 419 (1998) 623-631.

[5] R. R. Crittenden *et al.* Nucl. Instr. and Meth. A 368 (1996) 617-627.