Time over Threshold electronics for an underwater neutrino telescope

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Abstract

The use of Time over Threshold (ToT) digitization techniques for the treatment of the output signal of the PMTs of the KM3NeT detector is under consideration by the KM3NeT collaboration. In this technique the leading and trailing edge of the signal above a certain threshold are time stamped and the corresponding times are sent to the onshore acquisition system. More information can be obtained by applying the same scheme at multiple threshold levels. In this note we present the efficiency of such a digitization technique applied to signals provided by the HEllenic LYceum Cosmic Observatories Network (HELYCON) Extensive Air Shower detector. The hardware used has been designed by the Hellenic Open University (HOU) group and it is based on a High Precision Time to Digital Converter (HPTDC) chip developed at CERN and offering up to 32 channels with a digitization accuracy of 100ps. We describe the operation and performance of this electronics and we evaluate the reconstruction accuracy of PMT signals using data collected from Extensive Air Showers. Finally we report on our plans to use this electronics on Optical Modules proposed to be used in KM3NeT.

Key words: KM3NeT, HELYCON, Time over Threshold
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1. Introduction

The Time over Threshold (ToT) technique is being considered by the KM3NeT [1] collaboration for the digitization of the signals of the telescope's photomultipliers (PMTs), since that would require only a small amount of off-shore electronics, thus minimizing power consumption and maximizing reliability [2]. The technique is based on the time-tagging of the leading and trailing edge of the signal above a number of certain thresholds. These time values are then used for the reconstruction of the PMT pulses. We present the characteristics and operation of the electronics board developed for the implementation of the technique as well as the setup adopted for the board and ToT technique testing. The testing procedure was based on PMT signals generated by a HEllenic LYceum Cosmic Observatories Network (HELYCON) detector, as described in section 2. The HELYCON detector stations have also been proposed for the calibration of a deep-sea neutrino telescope [3]. The performance of the board and the accuracy of the reconstruction of the PMT signals are presented in section 3.

2. PMT Readout

2.1. *Time over Threshold*

The Time over Threshold (ToT) technique is based on the use of a Time to Digital Converter (TDC) that performs time-tagging of the leading and trailing edge of the PMT signal above a certain threshold. Particularly, the signal goes through a comparator that compares it against the desired

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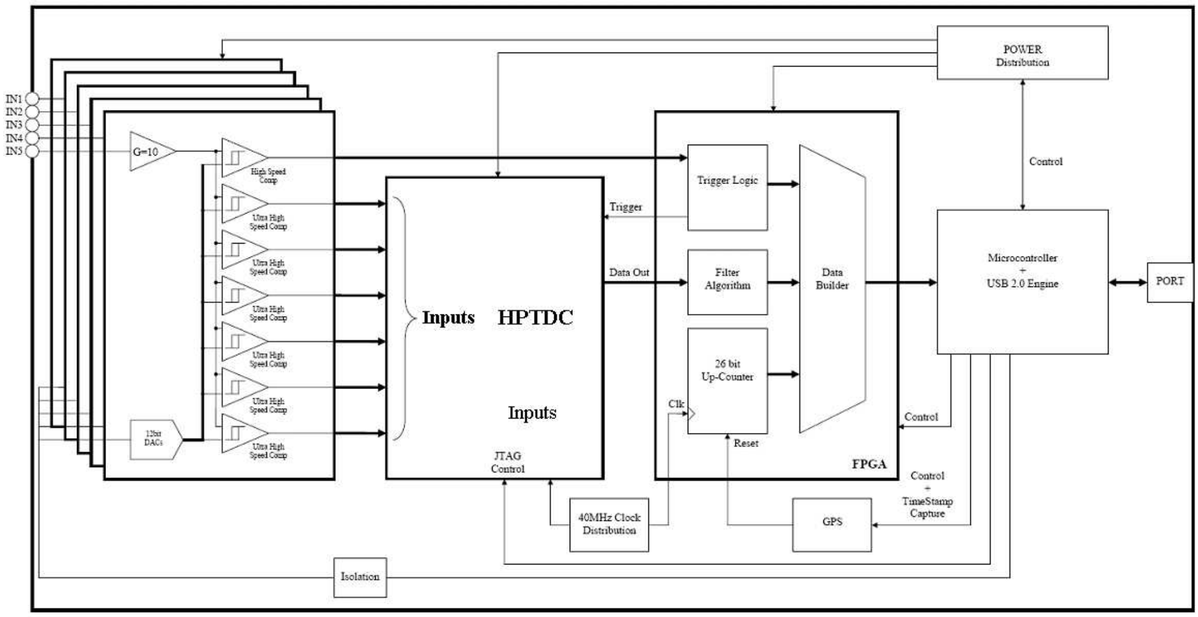

Fig. 1. Schematic of the HELYCON DAQ board

threshold. The output of the comparator is then fed to the TDC that performs the time-tagging of the leading and trailing edge. These values are subsequently used for the reconstruction of the pulse shape and its charge. The same scheme applied to more thresholds increases the efficiency of the technique significantly.

2.2. *Readout electronics*

The HELYCON data acquisition board (figure 1) is based on a High Precision Time to Digital Converter (HPTDC) chip developed at CERN [4]. The HPTDC accuracy is 25ps with 8 channels, while with 32 channels it is 100ps. The latter is the mode employed for the board, allowing for 6 channels per input, which correspond to 6 threshold values for each input signal. Each of the board's 5 signal inputs is driven to a set of 6 comparators after being amplified by a certain factor. The current version of the board exhibits different amplification factors (scale) of 1, 1, 1.5, 2.5 and 5, so that the best option can be selected, balancing the desire for a higher scale that will allow the recording of small pulses, but also for a smaller scale that will allow the recording of higher pulses. The outputs of the comparators are driven to the HPTDC, which performs the time-tagging of the threshold crossings. The time values from the HPTDC along with the GPS signal are, then, driven to the FPGA, which incorporates filter algorithms, the trigger logic and event-building algorithms. A USB controller handles the communication between the FPGA and the hosting computer. The power consumption of the HPTDC is around 0.5W, while the current version of the board has a power consumption of around 15W, which can be well reduced in the final version of the board.

Specially developed software allows the user to enable/disable of channels (thresholds), set the values of the thresholds, run basic calibration processes on the channels and, of course, perform data acquisition.

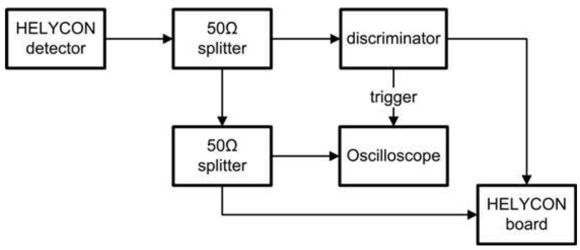

Fig. 2. Setup for board calibration

2.3. *Setup and operation*

Extended testing has been performed for the determination of the characteristics of the electronics (such as the exact values of the inputs scales and the channels offsets), the evaluation of the board performance and of the PMT signal reconstruction accuracy. The testing configuration chosen was based on the signal of the PMT of a HELYCON detector and is depicted in figure 2. The signal was split twice and fed to the board as well as to a high precision oscilloscope. The signal was also driven to a discriminator and the discriminator output was used to trigger the oscilloscope but was also recorded by the board. Thus, the identification of PMT pulses recorded by both the oscilloscope and the board can be achieved.

3. PMT charge estimation

3.1. *Board characteristics*

Before attempting to reconstruct the PMT signal, a number of characteristics of the board had to be determined. These include the exact values of the scales for each of the board's analog inputs, the offsets of each of the channels (a total of 30 channels, namely 6 channels for each input), the noise of each channel and the minimum threshold that can be applied to each of the channels (taking into account the respective noise level).

In order to do so, a DC voltage of the order of a few mV was applied to each of the board's inputs. The software's built-in Calibrate DC procedure was used, which increases the threshold for each channel by the minimum step (0.833mV) spanning the area defined by the user and saves the number of threshold crossings for each threshold value. The result is a Gaussian with mean the DC voltage applied to the input multiplied by the input's scale plus the channel's offset and a sigma indicating the noise of each channel. By applying different values of DC voltage to the inputs, the scale (multiplication factor) of each input and the offset of each channel can be determined.

Concerning the noise of the inputs, the minimum threshold that can be applied is 1.57mV for the 2.5 scale input, which corresponds to around 1/3 of the Minimum Ionizing Particle (MIP) for the HELYCON detectors and is very good for the timing analysis of the recorded pulses. The highest threshold for this input is 800mV (150-200MIP) but, of course, much higher pulses can be reconstructed using the times over threshold information [1]. The 5 scale input exhibits slightly lower (and the lowest among the 5 inputs) minimum threshold (1.42mV), but the higher threshold that can be applied to it is only 400mV decreasing the accuracy of the higher pulses reconstruction. Thus the 2.5 scale has been selected for the final version of the board.

3.2. *Charge estimation*

For the evaluation of the charge estimation efficiency of the Time over Threshold technique, extensive air showers data from a HELYCON detector collected with a high sampling rate oscilloscope, have been used for the generation of the ToT values corresponding to a set of thresholds (namely 3mV, 10mV, 20mV, 40mV, 70mV and 100mV). Subsequently, the plots of the measured charge versus the sum of the times over threshold were generated for the areas where 1, 2, 3, 4, 5 and 6 thresholds were crossed (all the areas are depicted in figure 3).

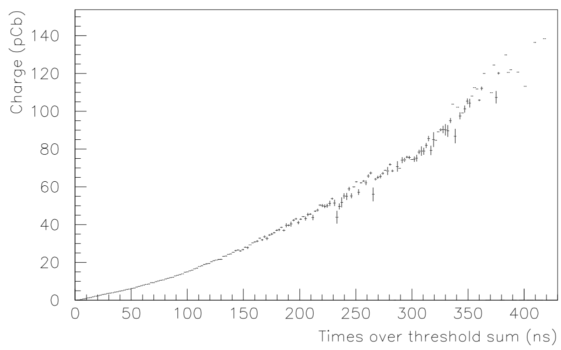

Fig. 3. The measured charge as a function of the sum of the times over threshold

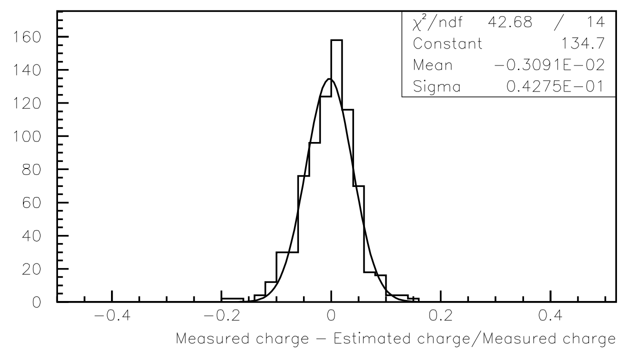

Fig. 4. The measured charge minus the estimated charge divided by the measured charge in the case that 4 thresholds have been crossed

Parameterizations were calculated for each of the areas (usually in the form of a polynomial function),

[1] Pulses exceeding the 800mV limit are not distorted but just truncated by means of a zener diode

that were then used for the calculation of the charge of the pulses by using the values of the times over threshold. By comparing the calculated charge versus the measured charge, the charge estimation resolution can be evaluated. Figure 4 shows the distribution of the measured charge minus the estimated charge divided by the measured charge for the case that four of the thresholds have been crossed. The estimated resolution in this case turns out to be 4.3%. The respective pull distribution is depicted in figure 5 and exhibits a sigma of 1.04 ± 0.07 that proves that the estimation is unbiased.

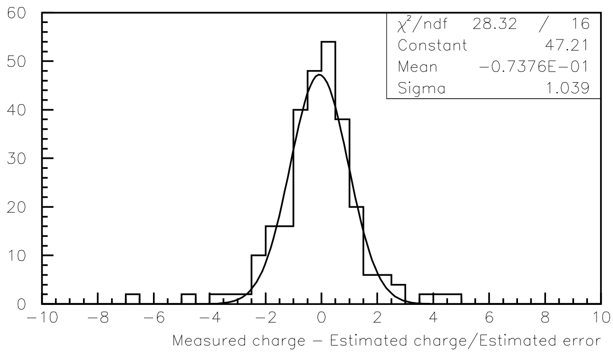

Fig. 5. The measured charge minus the estimated charge divided by the estimated error in the case that 4 thresholds have been crossed

Figure 6 depicts the charge estimation resolution versus the number of thresholds crossed. Of course, as the number of thresholds crossed increases, the resolution gets better. In the case all 6 thresholds have been crossed, the resolution seems worse because the highest pulses have been truncated by the oscilloscope, which was setup to record pulses up to 150mV with the best resolution.

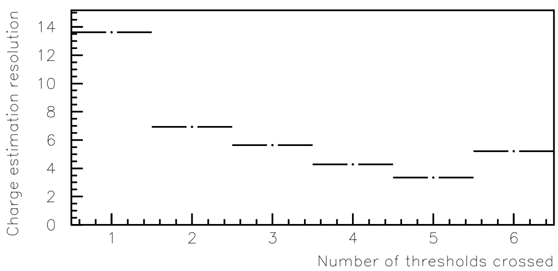

Fig. 6. The charge estimation resolution (%) versus the number of thresholds crossed

Figure 7 depicts a pulse as recorded by the oscilloscope (line), while the dots correspond to the threshold crossings recorded by the board. The work for the evaluation of the Time over Threshold technique and its application on the data recorded by the HELYCON board is on going. More threshold values combinations have to be examined and tested on the board and effective algorithms developed for double pulses separation.

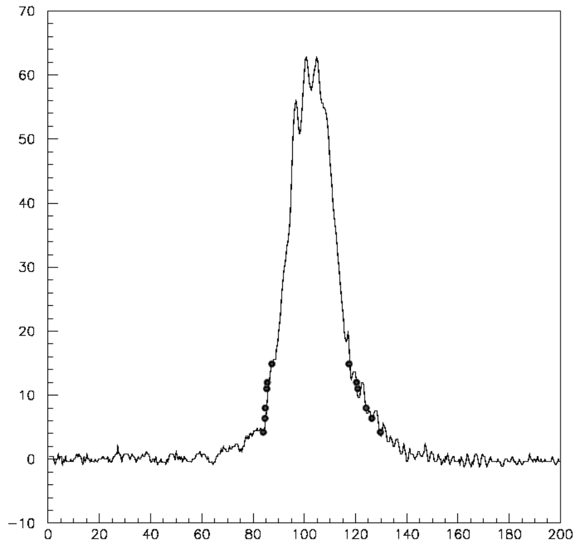

Fig. 7. A pulse as recorded by the oscilloscope (line) and by the HELYCON board (dots)

4. Conclusions

The Time over Threshold technique exhibits a charge estimation resolution down to 3-4% for higher pulses, which is more than enough for both the HELYCON experiment and the KM3NeT neutrino telescope.

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