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OMEGA SiPM readout ASICs

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► **To cite this version:**

S. Ahmad, S. Blin, S. Callier, J.B. Cizel, S. Conforti, et al.. OMEGA SiPM readout ASICs. SiPM workshop: from fundamental research to industrial applications, Oct 2019, Bari, Italy. pp.164628, 10.1016/j.nima.2020.164628 . hal-02981274

HAL Id: hal-02981274

<https://hal.science/hal-02981274>

Submitted on 17 Oct 2022

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SiPM SPECTRUM with Autotrigger

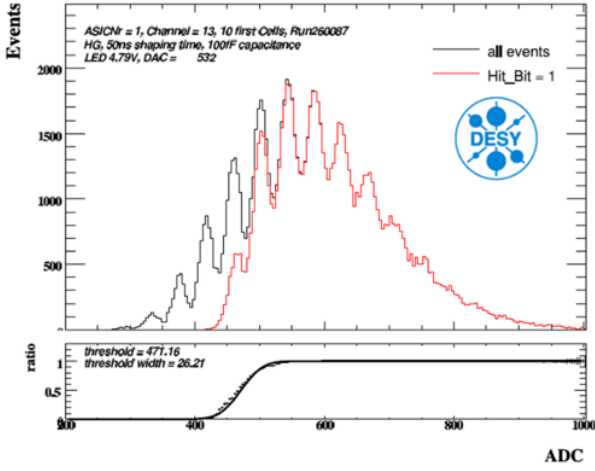


Figure 2: Low light spectrum obtained with the CALICE prototype readout with SPIROC2B.

More than 2000 chips were produced and equip a large size calorimeter prototype, extensively studied in test beam by the CALICE collaboration.

2.2. CITIROC

A variant of the chip has been designed for the ASTRI collaboration who develops SiPM-based telescopes for the Cerenkov Telescope Array (CTA) experiment [3]. The analog part of SPIROC has been conserved, while the digitization and digital part were removed and are performed externally in order to reduce the dead time. A peak sensing holder has been introduced in order to be un-sensitive to the dispersion in the time of arrival of the different photons from the Cerenkov image [4].

The block diagram of the chip is shown in Figure 3. It follows a similar architecture than the SPIROC chip, without the digitization, which is performed outside the chip at 2 MHz [5].

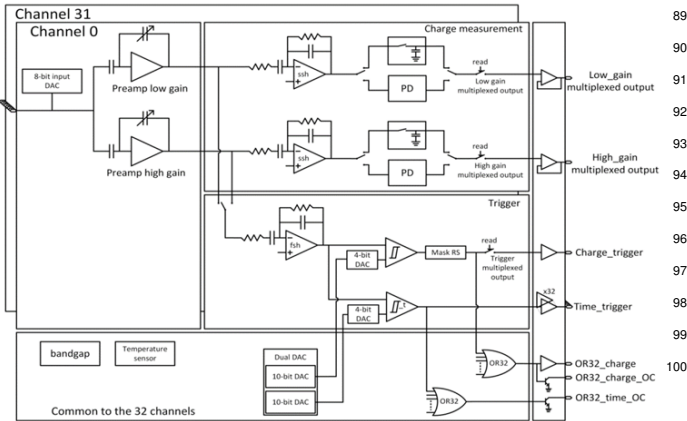


Figure 3: Block diagram of CITIROC ASIC.

A large telescope prototype has been produced, equipped with SiPM 8x8 arrays, readout by CITIROC ASICs. Good results are obtained [6], as shown in Figure 4.

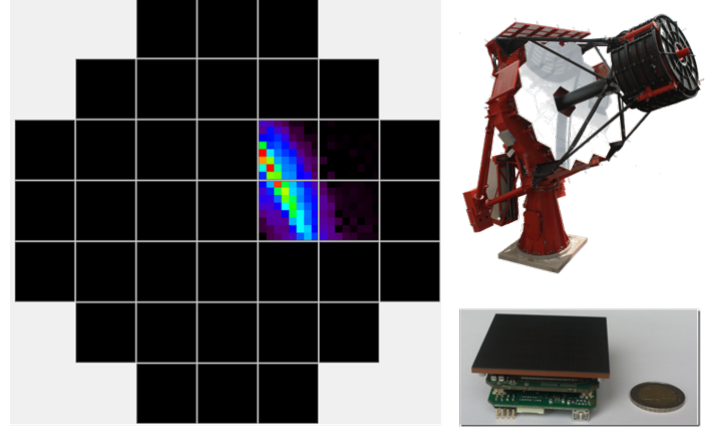


Figure 4: ASTRI telescope prototype for Cerenkov imager equipped with CITIROC ASICs.

3. ASICs for timing: TRIROC and PETIROC

The growing interest for sub-nanosecond measurements combined with the fast response of SiPMs make them ideal sensors for timing detectors. However, for small amounts of light and therefore small signals, the timing accuracy is dominated by the electronics jitter and there is a strong push for getting very high speed readout ASICs.

3.1. General considerations for timing

The timing accuracy of a detector depends on several factors, but is usually dominated by the electronics jitter at small amplitude. The electronics jitter (j) is the translation in the time domain of the electronics noise (N) when crossing the threshold of a discriminator due to the finite signal slope (dV/dt). To first order, the jitter is simply the ratio of the rms noise over the signal slope and is expressed in ns or ps. As the signal slope is proportional to the bandwidth (BW) and the rms noise scales as the square root of the bandwidth, it is often believed that the jitter improves by increasing the bandwidth, the jitter scaling as $1/\sqrt{BW}$.

This is however not really the case for capacitive sensors which produce current pulses, such as SiPMs (as well as many other photodetectors). In that case, the current signal which has a finite duration (t_d FWHM) gets integrated on the sensor capacitance (C_d) for the highest frequency components and the risetime on the preamplifier input is simply t_d . Having a very fast preamplifier only increases the output noise but does not change the output rise time. Conversely, if the preamplifier is too slow, the output risetime is the convolution of the current duration (t_d) and the preamplifier risetime (t_{PA}), which is usually simplified as the quadratic sum of the two time constants. The signal amplitude scales as Q/C_d .

Therefore the jitter can be expressed as:

$$j = \frac{N}{dV/dt} = \frac{e_n}{\sqrt{2}t_{10-90,PA}} \cdot \frac{C_d \sqrt{t_{10-90,PA}^2 + t_d^2}}{Q_{in}} = \frac{e_n C_d}{Q_{in}} \cdot \sqrt{\frac{t_{10-90,PA}^2 + t_d^2}{2t_{10-90,PA}}}, \quad (1)$$

101 in which e_n is the preamplifier noise spectral density, C_d the de-138
 102 tector capacitance, t_d the signal duration (FWHM), t_{10-90_PA} the-139
 103 preamplifier alone rise time (10-90%) and Q the signal charge. 140

104 As can be seen in Figure 5, the jitter can be minimized by-141
 105 choosing a preamplifier rise-time t_{PA} equal to the current dura-142
 106 tion t_d , however the optimum is rather shallow and it has to be-143
 107 balanced with the reduced sensitivity, as the minimum threshold-144
 108 increases when increasing the speed. Indeed, being twice faster-145
 109 increases the minimum threshold by 40%, whereas being twice-146
 110 slower reduces the minimum threshold by 30%, while deterio-147
 111 rating the optimum jitter by only 10%. It is therefore usually-148
 112 preferable to be slightly too slow than too fast. 149

113 At the optimum preamp speed, the jitter is simply given by:150
 114 $j = e_n \cdot C_d \sqrt{t_d}/Q$. 151

115 For SiPMs, the jitter benefits from the large charge collected,152
 116 (hundreds of fC per photoelectron) and from the very short cur-153
 117 rent duration (<100 ps). It is however penalized by the large
 118 sensor capacitance (in the 100 pF range), especially for large
 119 area photosensors. It is thus expected to obtain the best timing
 120 resolution for the smallest devices and measurements in Figure
 121 8 show that this is indeed the case.

122 As an example, for a 300 pF SiPM with a gain of 10^6 , as-
 123 suming a good preamplifier with a noise spectral density of 1
 124 nV/\sqrt{Hz} , a jitter of 20 ps for single photoelectrons could be ex-
 125 pected. With a current pulse duration of 100 ps, the optimum
 126 preamplifier risetime is equal to 100 ps, which corresponds to a
 bandwidth of 3.5 GHz.

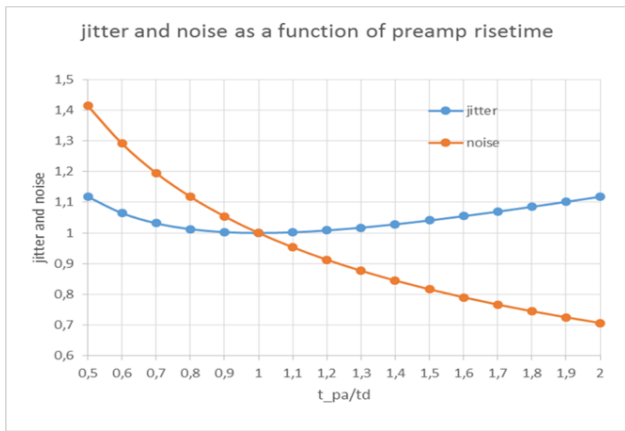


Figure 5: Jitter and noise as a function the ratio of preamplifier rise time over input current duration.

128 3.2. TRIROC

129 TRIROC is a 64 channel ASIC designed for tri-modal
 130 PET/MRI/EEG brain imaging in the framework of the Trimage
 131 European project [7]. Its architecture is similar to PETIROC
 132 described below, but with twice the number of channels and a
 133 slightly lower speed [8]. For lack of space, the paper will con-
 134 centrate on PETIROC. 167

135 3.3. PETIROC

136 PETIROC is a 32 channel ASIC which has been optimized-171
 137 to provide 1 GHz bandwidth for timing applications and PET-172

imaging [9]. The block diagram is shown in Figure 6. It is
 composed of a high speed voltage sensitive preamplifier cou-
 pled directly to a high speed discriminator. The chip takes full
 advantage of the SiGe technology to achieve high speed and
 low noise. The input preamplifier impedance is 200Ω for high
 frequencies and a 50Ω impedance can be obtained by adding a
 68Ω resistor outside if needed. An 8-bit DAC allows to adjust
 the input voltage channel-wise over 1 V span, in order to com-
 pensate the dispersion in overvoltage in SiPM matrixes. The
 discriminator outputs can be used directly to drive an external
 TDC which allows to reach the lowest time resolutions and
 highest rates. An internal TDC is also available for lower rate
 applications, providing a time resolution around 50 ps.

A slower channel also provides charge information for the
 energy measurement in PET applications. Otherwise time-over
 (threshold technique (TOT) can be used for timewalk correction
 on smaller signals.

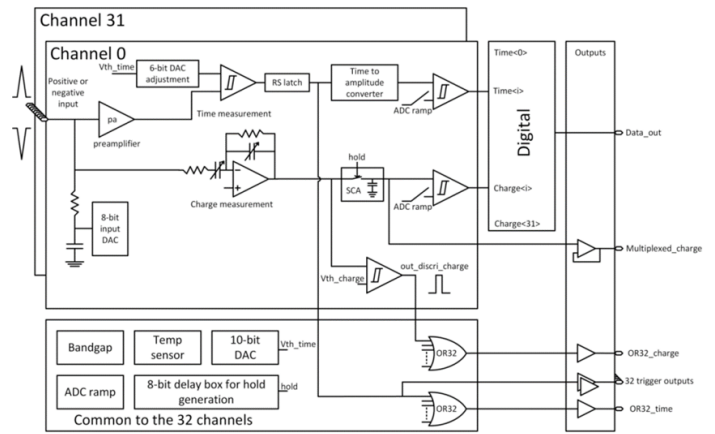


Figure 6: Bloc diagram of the PETIROC ASIC.

154 The ASIC speed is in good agreement with expectations,
 155 with a measured bandwidth of 0.9 GHz for the full chain, from
 156 input to discriminator output. The noise is also very low, allow-
 157 ing to set a minimum threshold at 1 mV on the input, as shown
 158 in Figure 7, corresponding to 100 fC on 100 pF. The best jitter
 159 performance, down to 15 ps, is obtained with external TDC as
 160 the digital noise from the internal TDCs increase the jitter to 45
 161 ps. 162

163 The performance for single photoelectrons jitter with various
 164 SiPM is shown in Figure 8, where values down to 90 ps FWHM,
 165 corresponding to 40 ps rms are achieved.

166 4. Conclusions

167 The use of high performance ASICs has been a key element
 168 for getting the best performance of SiPMs and has allowed
 169 their successful use in large detectors. OMEGA and WEEROC
 have developed several multi-channels chips such as SPIROC,
 CITIROC, TRIROC or PETIROC which allow to get compact
 performant photodetectors used in several large experiments.

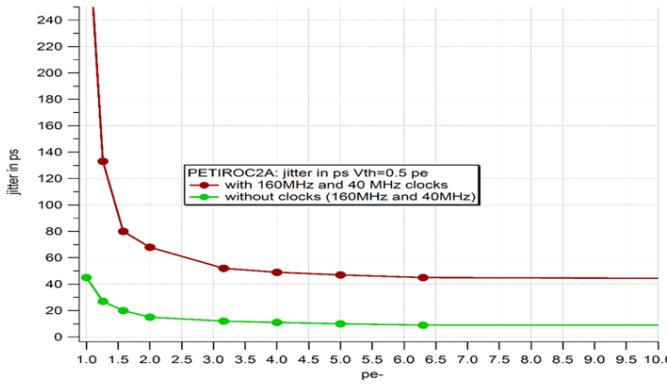


Figure 7: Jitter as a function of signal amplitude measured with PETIROC ASIC.

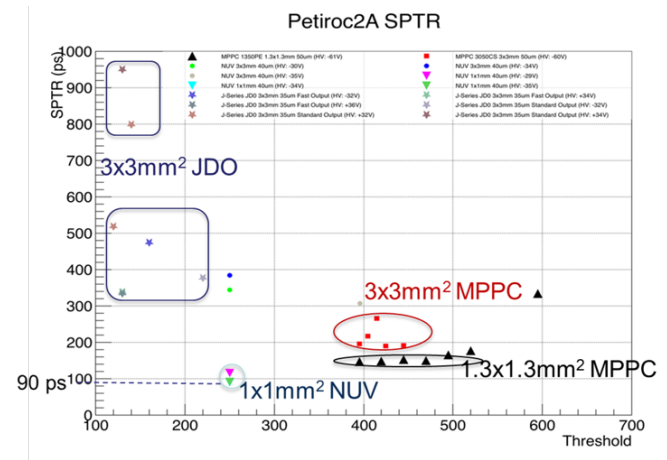


Figure 8: Single photon time resolution (SPTR) measured with PETIROC on various SiPMs.

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173 **Acknowledgements**

174 The help of WEEROC and CAEN companies is gratefully
175 acknowledged.

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