The PH32 Readout Integrated Circuit

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Abstract. *The PH32 readout chip has been developed for measurement of X-rays, beta radiation and charged ions including alpha particles. The chip has been manufactured in a commercial 180 nm CMOS technology and its applications include dosimetry, spectroscopy, medical diagnostics and radiotherapy. Its main capability with connected sensor are hit counting and measurement of the deposited charge in the range from 2.5 ke$^-$ to 10 Me$^-$ in two operational modes. The signal charge collected by silicon strips can be determined to an accuracy of about 1500 e$^-$ for a chip calibrated for the charge of 50 ke$^-$. This paper is focused on the measurement of the channel response to the injected charge. The measurements presented here include channel uniformity, gain, noise, linearity and dispersion during chip calibration.*

Keywords: Silicon radiation detector, Front-end chip, 180 nm, CMOS

1. Introduction

In recent years there is a steadily growing demand for more sophisticated, precise and at the same time flexible detection systems of diverse radiation fields used in numerous practical applications. The “distributed brain” of such systems constitute front-end chips. The variety of different applications and demands corresponds to the used technology and chip architecture. The readout chip is the most crucial part of every such detection system.

The driving force for the development are R&D projects of large high-energy physics experiments at CERN, e.g. ATLAS or CMS. The most common solution are hybrid pixel detectors consisting of readout chips and silicon sensors, connected together by bump-bonding. The technology used for readout chips FE-I3 [1], FE-I4 [2] or MediPix [3], [4] developed at CERN has a large application potential. However, those chips are too large in terms of relatively high amount of channels and they need expensive and complicated interconnection technology (bump-bonding). This is a limiting factor for many applications.

Chips of the PH32 series can serve as the readout of strip or pad sensor arrays. Such sensor granularity is still sufficient for numerous applications, allowing to replace the expensive bump-bonding by much cheaper wire bonding. The detection system with PH32 chip has substantially higher radiation tolerance than the common electronics for commercial applications, thus PH32 chips can be used in medical applications like diagnostics and radiotherapy, dosimetry or spectroscopy with the minimum amount of hardware and for an affordable price. This article summarizes the overall chip description and evaluation of the chip response to the charge injected during the chip calibration.

2. Chip Architecture

A block schematic of the chip is shown in Fig. 1. It contains 32 identical readout channels with analog inputs, which can be connected to 32 sensitive silicon strips. The chip is designed to

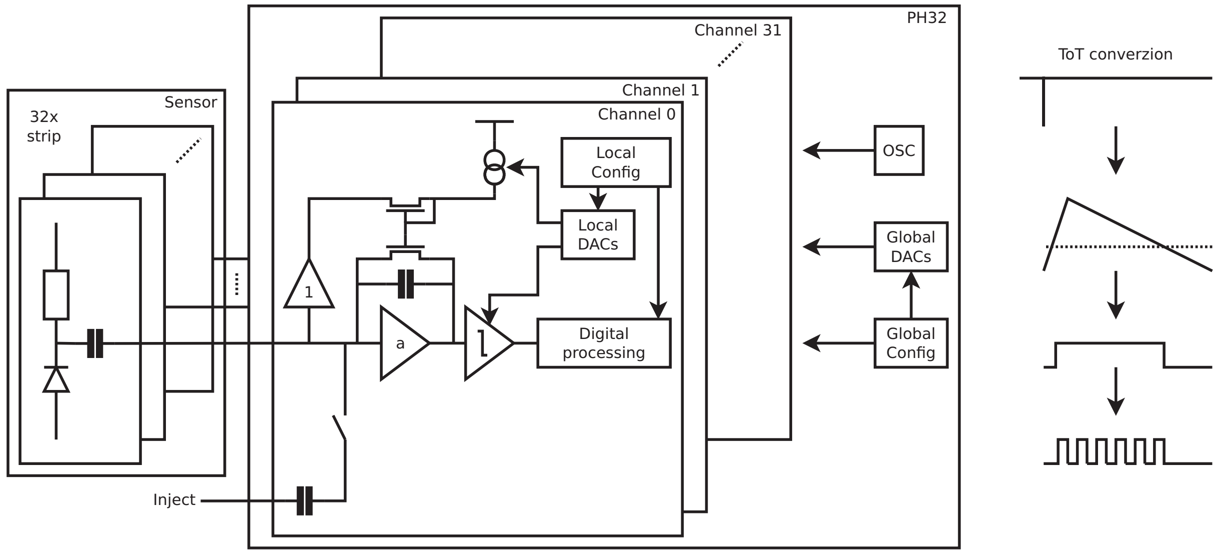

Fig. 1: Block schematic of the PH32 chip.

collect the negative charge. Signal from the sensor is led through an AC coupling capacitor to the input of the channel processed by the Charge Sensitive Amplifier (CSA).

In order to cover the dynamic range of the charge, we can adjust the CSA sensitivity in two modes: High Gain Mode (HGM) for soft X-rays and beta radiation and Low Gain Mode (LGM) for ions. Each channel includes Digital to Analog Converters (DAC) for tuning electrical properties of the CSA of each channel separately. Signal from the CSA is led to a discriminator with adjustable threshold and to a digital part. The chip can be configured to work in the hit counting mode or in the mode for particle energy measurement by the method known as the Time over Threshold (ToT) mode with sampling frequency in the range of tens to hundreds of MHz. The power supply voltage of the chip is 1.8 V. Static consumption is less than 150 µW for analog part and dynamic consumption is approximately 100 µW for digital part per channel. The total power consumption is less than 15 mW.

Threshold Tuning

Detection performance like gain, noise, linearity, dispersion between measurement channels, etc., is closely related to the analog part of the channel. In order to obtain relevant data from the sensor, the analog part has to be calibrated with the help of the charge injected from an external generator to the input. This substitutes the signal from the sensor and allows to perform calibration to obtain the minimal dispersion between individual channels. A specific charge in range from 2.5 ke^- to 100 ke^- for HGM and from 350 ke^- to 10 Me^- for LGM is used for calibration with respect to silicon sensor thickness (525 µm) and desirable sensitivity to X-rays but also to alpha particles. Calibration is performed simultaneously with the change of DAC values to adjust discriminator and CSA operation.

3. Results

Here we present the analysis of the PH32 chip response on the charge injection at the chip input. This process allows us to reveal the basic parameters of the chip. All measurements were done without sensor connected to the chip.

In order to determine the dispersion of ToT values between individual channels, various charge values have to be injected repeatedly to all channels during one measurement. The HGM

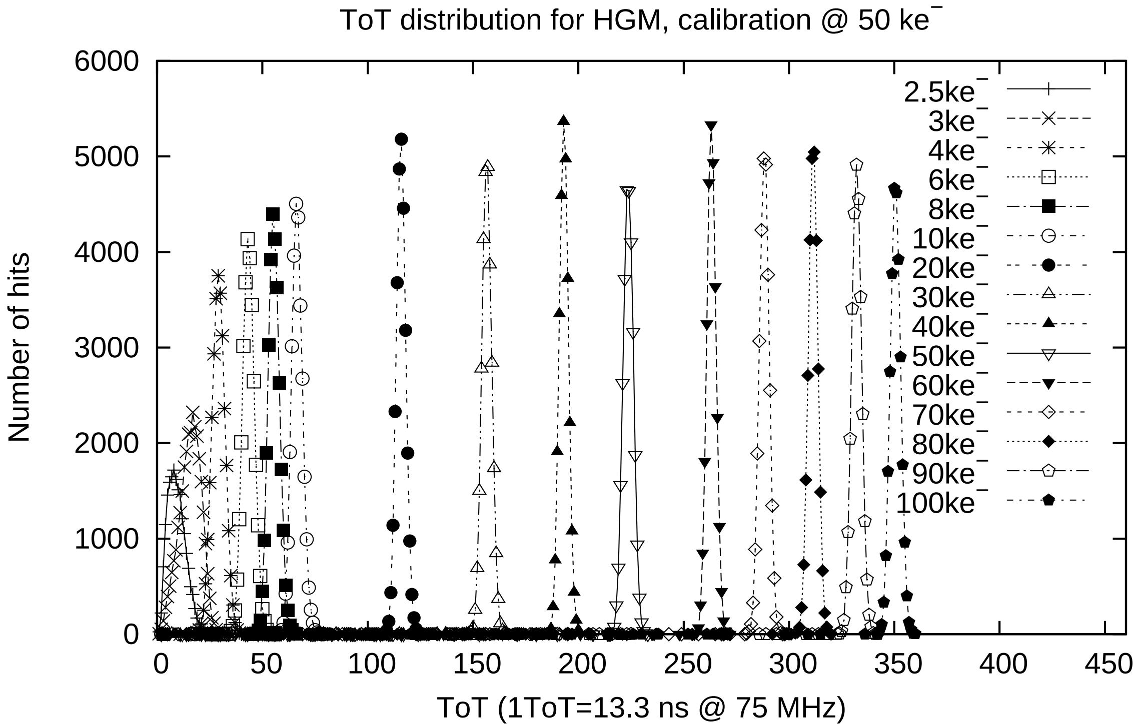

Fig. 2: Response to 1000 injections for injected charge varying from 2.5 ke⁻ to 100 ke⁻. The chip was operated in HGM and calibrated for a charge of 50 ke⁻. The curves represent the sum of signal from all channels.

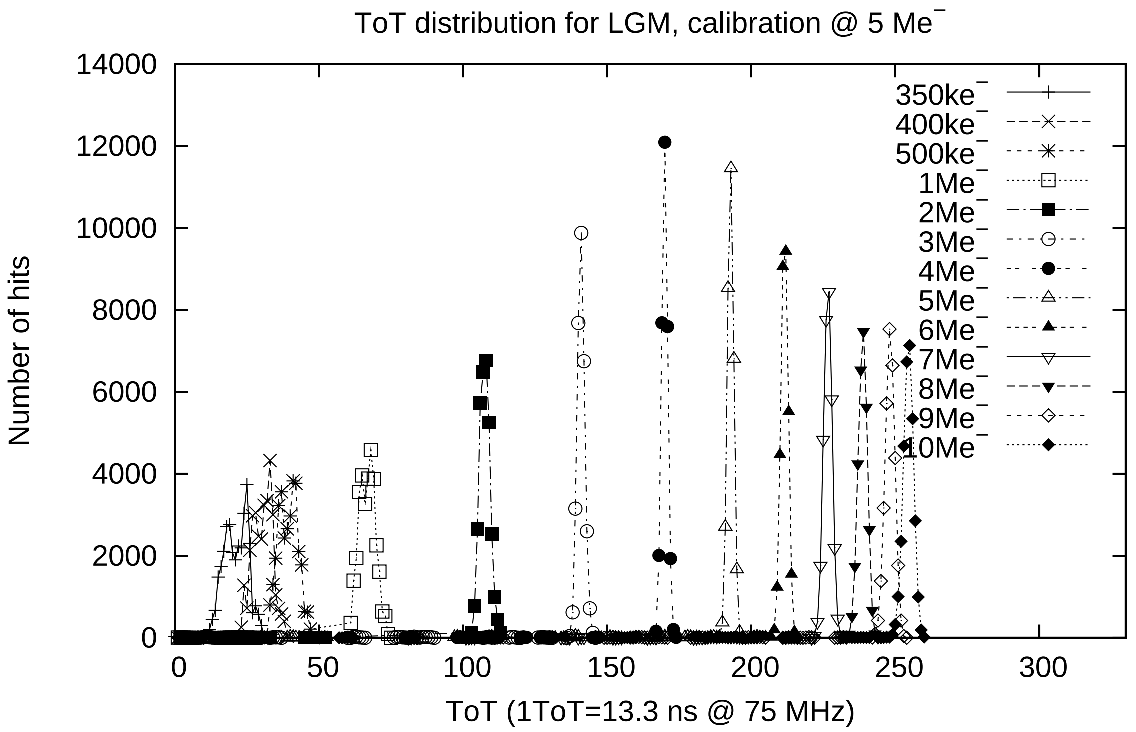

Fig. 3: Response to 1000 injections for injected charge varying from 350 ke⁻ to 10 Me⁻. The chip was operated in LGM and calibrated for a charge of 5 Me⁻. The curves represent the sum of signal from all channels.

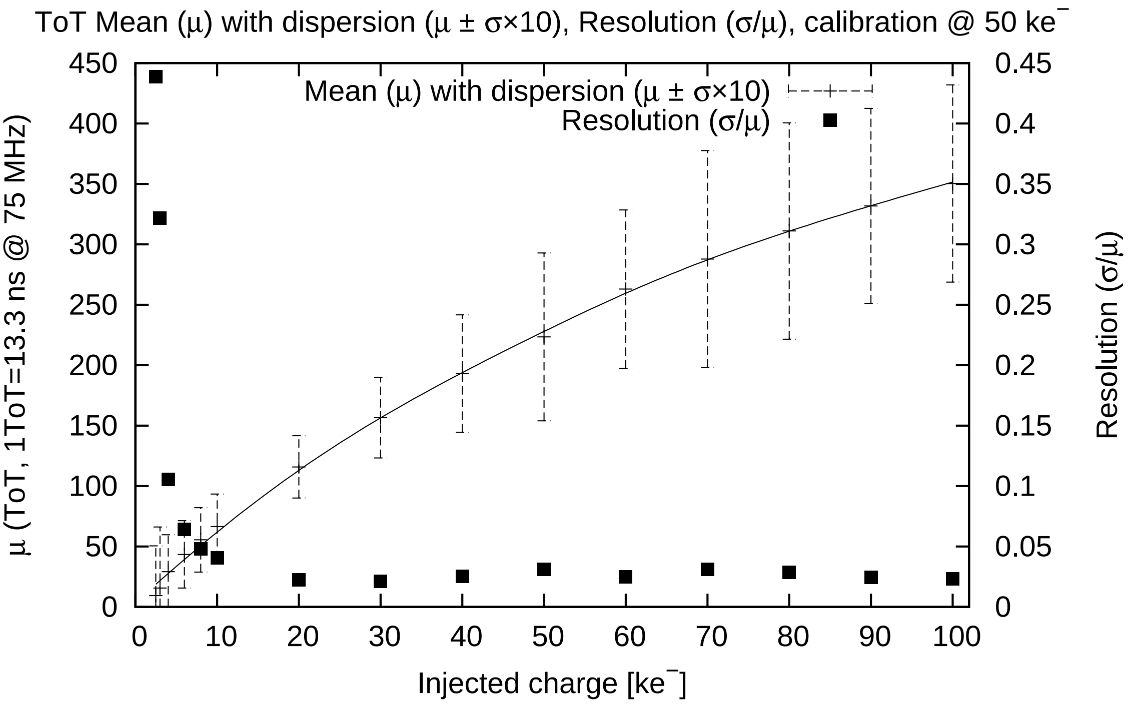

Fig. 4: Mean value of ToT $F(\mu)$ and resolution (σ/μ) as a function of the injected charge (1000 injections with various value of injected charge) in HGM, for a chip calibrated at 50 ke$^-$.

calibration has been done with the charge injection in the range from 2.5 ke$^-$ to 100 ke$^-$ for the chip calibrated for 50 ke$^-$charge (shown in Fig. 2). The LGM calibration has been done with the charge injection in the range from 350 ke$^-$ to 10 Me$^-$ for the chip calibrated for 5 Me$^-$charge (shown in Fig. 3). The results for both modes are qualitatively comparable. Each individual peak in Fig. 2 and Fig. 3 belongs to a specific charge and the width of the peak represents fluctuations of response between individual channels mainly due to the electronic noise, imperfect calibration method and quantization error. A significant indicator of the chip performance is the resolution. Fig. 4 represents mean and standard deviation of the measurement performed in HGM. The resolution depends directly on the sample frequency from internal oscillator operated at 300 MHz, which can be lowered by an implemented divider. However, noise contamination has been observed for higher frequencies due to the voltage drop on power rails inside the chip. The measurement was provided for a 75 MHz sample frequency.

4. Conclusions

The PH32 readout chip is suitable for measuring X-rays, beta radiation and alpha particles and can be used in dosimetry, spectroscopy, medical diagnostics and radiotherapy. The PH32 is able to measure the signal in a wide range in two separate operational modes. Both modes demonstrate very good performance. The signal charge collected by silicon strips can be determined to the accuracy of about 1500 e$^-$ for a specific calibration charge of 50 ke$^-$ in HGM and approximately 180 ke$^-$ for a specific calibration charge of 5 Me$^-$ in LGM (at 75 MHz sampling frequency). The noise is approximately 3 ke$^-$ for specific calibration charge in HGM. The chip indicates some problems like voltage drop due to high sampling frequency and crosstalk between digital and analog parts. These will be solved in the next version of the chip along with the higher noise reduction.

References

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