Pulse Shape Analysis for a New Pixel Readout Chip

James Kingston

University of California, Berkeley

Supervisors: Daniel Pitzl and Paul Schuetze

September 7, 2017

Abstract

The ROC4SENS readout chip is designed for testing 50 μm x 50 μm pixel sensors. Before sensors can be bump bonded to the chip, pixel response to various calibration pulses must be well understood at different input settings. The default peaking time for a pulse readout from the chip was measured to be 35 ns. By adjusting voltages in the pixel circuitry on the readout chip this peaking time was extended to 92 ns. This extension is crucial for testing at the DESY test beam which has a trigger which could exceed 40 ns.

Table of Contents

Introduction

The ROC4SENS is a readout chip designed to test the sensor part of a hybrid pixel detector. It contains a pixel matrix of 155 x 160 pixels with a pitch of 50 μm x 50 μm [1]. The pixels in the CMS tracker are currently 150 μm x 100 μm, so the chip is made for testing smaller pixels which may eventually replace the current sensors.

The bump pad of each pixel is connected to a preamplifier and then a shaper. Even when there are no pixel sensors bump bonded to the readout chip a calibration pulse can be sent to the pixels (together or individually) for testing.

An important aspect in developing new pixel detectors is evaluation of sensors at a test beam. A typical test beam setup involving scintillation triggers which take a few dozen nanoseconds for triggering. The ROC4SENS uses the same amplifier design as the current CMS pixel detector. These amplifiers have an intrinsically fast peaking time of about 35 ns.

However, the pulse shape is highly dependent on potentials in the amplifier feedback circuitry that can be directly controlled by the user. This report outlines the experimental procedure and results of testing the dependence of various features of the pulse shape (e.g. peaking time, pulse discharge time, peak height) on the variable input parameters of the chip, such as the potentials across the preamplifier and shaper feedback resistor, analogue supply voltage for their operational amplifier, and finally the amplitude of the calibration pulse.

Background

Readout Chips for Hybrid Pixel Detectors

Silicon pixel sensor arrays are often arranged in a matrix pattern with over 100 tightly packed rows and columns. When an energetic particle shoots through a pixel, an electron hole pair is created, generating a current. In a hybrid pixel detector, the array of sensors are connected to a single readout chip using the bump bonding technique (See Figure 1). A readout chip is manufactured for a specific pixel size and spacing. In the CMS pixel detector, readout chips are paired with 80 x 52 = 4160 pixel arrays of pitch 150 μm x 100 μm. To test smaller sensors, new readout chips with smaller pixel sizes are necessary for reading out the signals.

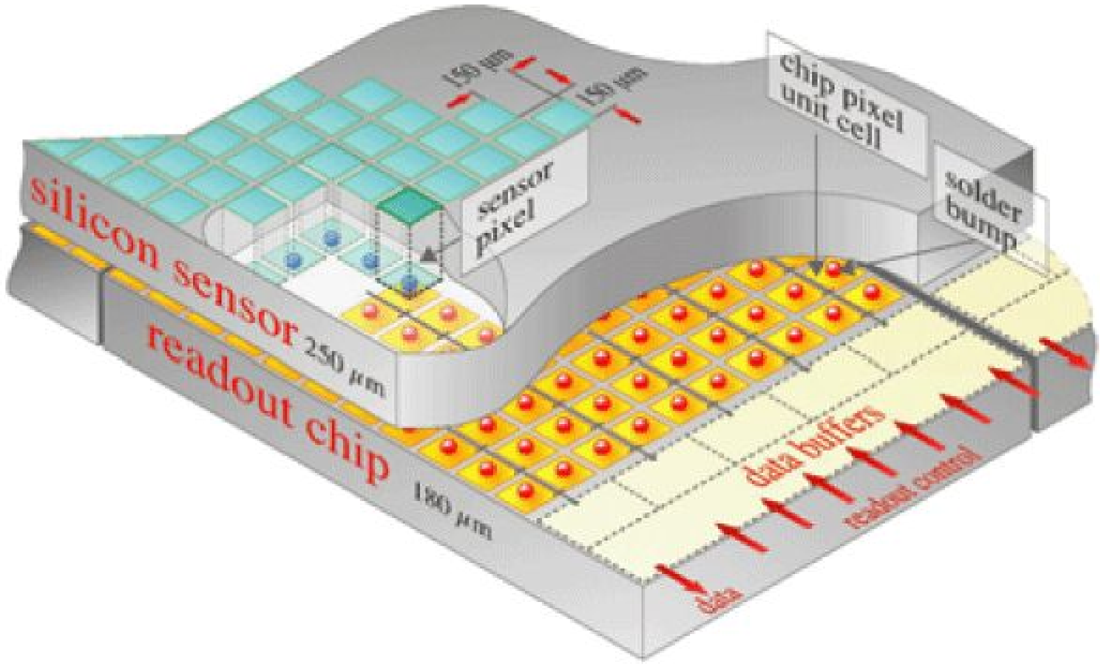

Figure 1: Bump bonding between a readout chip and silicon sensors. The readout chip has a matrix of solder bumps which align with the sensor pixels that compose the entire detector. [3]

ROC4SENS

The ROC4SENS is a new readout chip with 155 columns and 160 rows. The pixel pitch is 50 µm x 50 µm, which allows for testing of silicon sensors for a variety of experiments, including smaller pixels for the CMS pixel detector. The chip is 9.80 mm x 7.80 mm and has 35 wire bond pads for transmitting signals (See Figure 2). Each pixel on the ROC4SENS is composed of two signal inputs: a bump pad for bonding to a sensor and a calibration pulse for testing without a sensor (See Figure 3). These inputs connect to a preamplifier and shaper, the latter of which restores the pulse to the baseline. The pulse continues to a sample and hold capacitor, which can be disconnected by a hold signal after a user-controllable amount of time from the trigger. Every column of pixels feed into a gyrator and amplifier for a final analogue output.

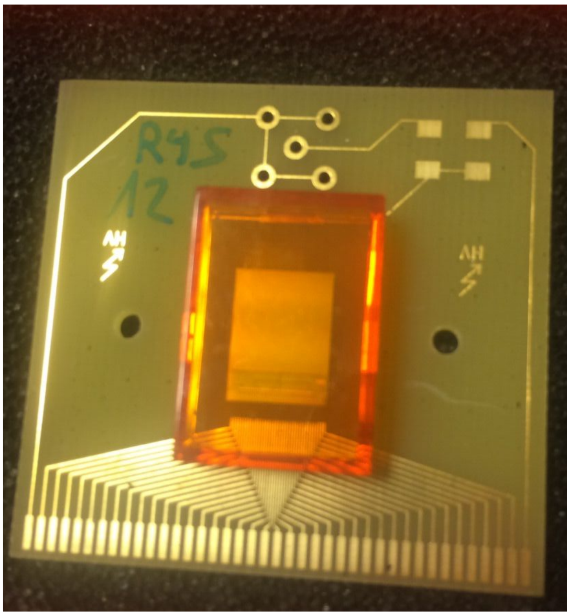

Figure 2: The ROC4SENS in the laboratory. For testing it has an orange cover for protection and sits atop a carrier board. The 35 wire bonds connect the readout chip to the carrier board.

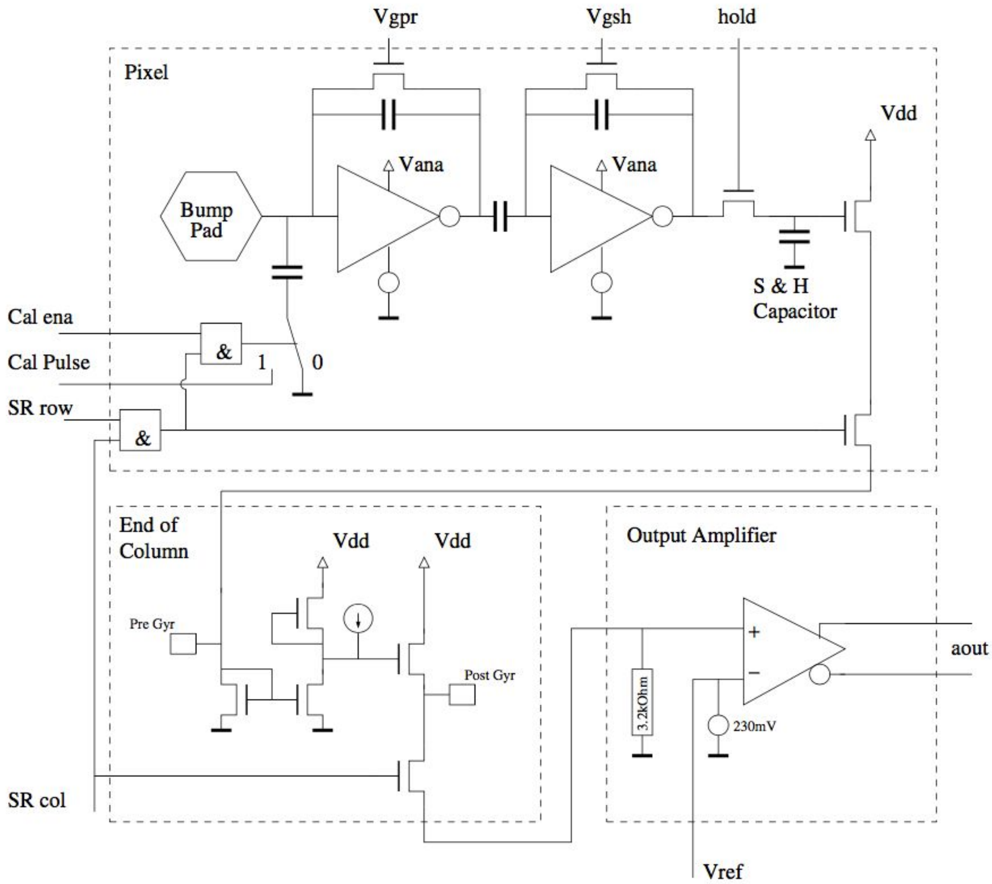

Figure 3: Schematic of the ROC4SENS: Every pixel on the ROC4SENS has an input for a calibration pulse as well as a bump pad for a pixel sensor. The signal passes through a preamplifier and shaper, and then the hold is used to specify a delay before continuing the signal to the column gyrator and finally the output amplifier. [2]

Experimental Setup and Procedure

To run preliminary tests on the ROC4SENS, the chip is inserted into an adaptor board. The chip periphery has 35 wire bond pads which send and receive potentials signals to and from the adaptor board. The adaptor board is connected to a digital testboard (DTB) containing an FPGA, which is in turn connected to a user-controlled computer via USB, as shown in Figure 4 below.

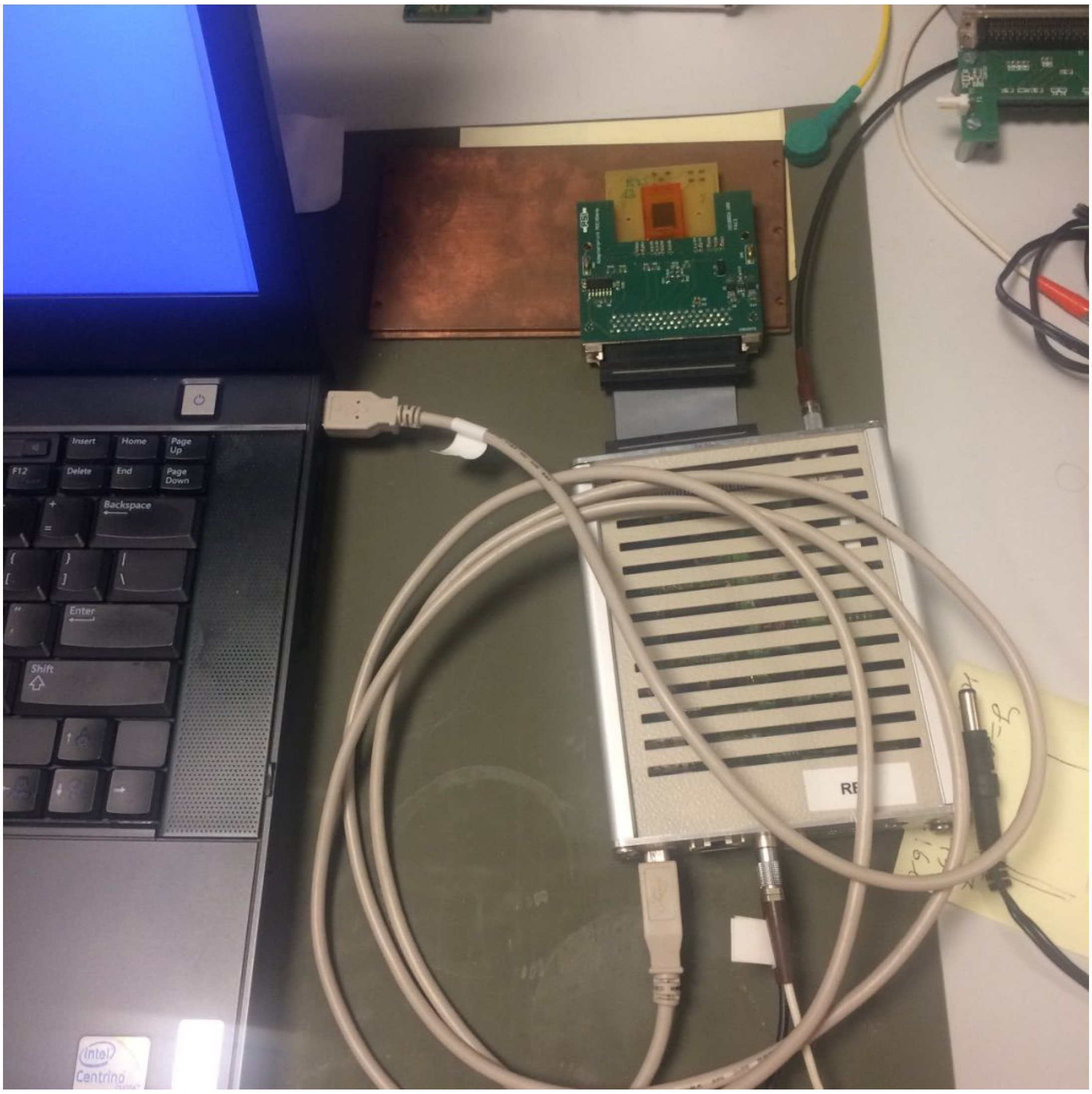

Figure 4: The computer reads in and sends out information to the DTB via USB, which is connected to an adaptor board that is plugged into the ROC4SENS carrier board. The LEMO cables send analogue and digital signals from the DTB to an oscilloscope. Individual pixel pulses can be observed for debugging.

Pulse Shape Acquisition

A program was written by engineers at PSI to send firmware commands to the ROC4SENS and DTB directly from the computer, such as setting the potential of various components of the readout chip and reading in data from pixels. One such command sets the hold delay for the pixel analogue outputs: the input range for this command is 0 to 255, with each digital unit corresponding to a delay of 6.25 ns (Thus covering a full range of 1.6 μs). To obtain a pulse shape plot I made a new command that iterates over the 0-255 hold range for a 0 mV calibration pulse and records every pixel output (to get the noise, colloquially referred to as the pedestal), then iterates again over the hold range at a user-defined calibration pulse. For each pixel and hold delay combination the pedestal is subtracted from the output that was obtained from the non-zero calibration pulse. The 24,800 values for each hold delay are averaged, resulting in 256 data points that reflect a pulse height in 6.25 ns increments. These data points can be plotted to obtain the outgoing pulse in response to a calibration pulse. Figure 5 is an example of such a pulse shape with the default ROC4SENS settings.

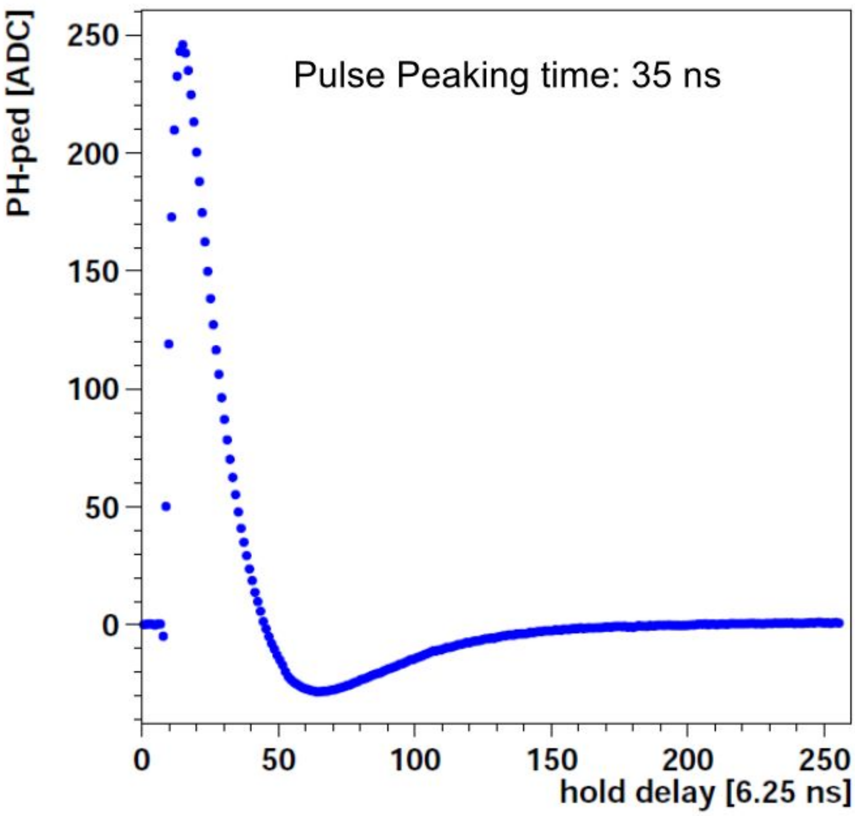

Figure 5: The default values for the ROC4SENS include 600 mV across the feedback resistor voltage for the preamplifier and 630 mV for the shaper. The analogue voltage is 2 V and the calibration pulse has an amplitude of 400 mV. The peaking time is 35 ns.

Pulse Fitting

A program was written in C++ to fit these pulse shapes to the product of a rising and falling exponential (the rise comes from the preamplifier, the fall comes from the shaper). The program was modified to record the peak pulse height, peaking time, and time over threshold, which was defined to be the time the pulse height was over the first nonzero value (See Figure 6).

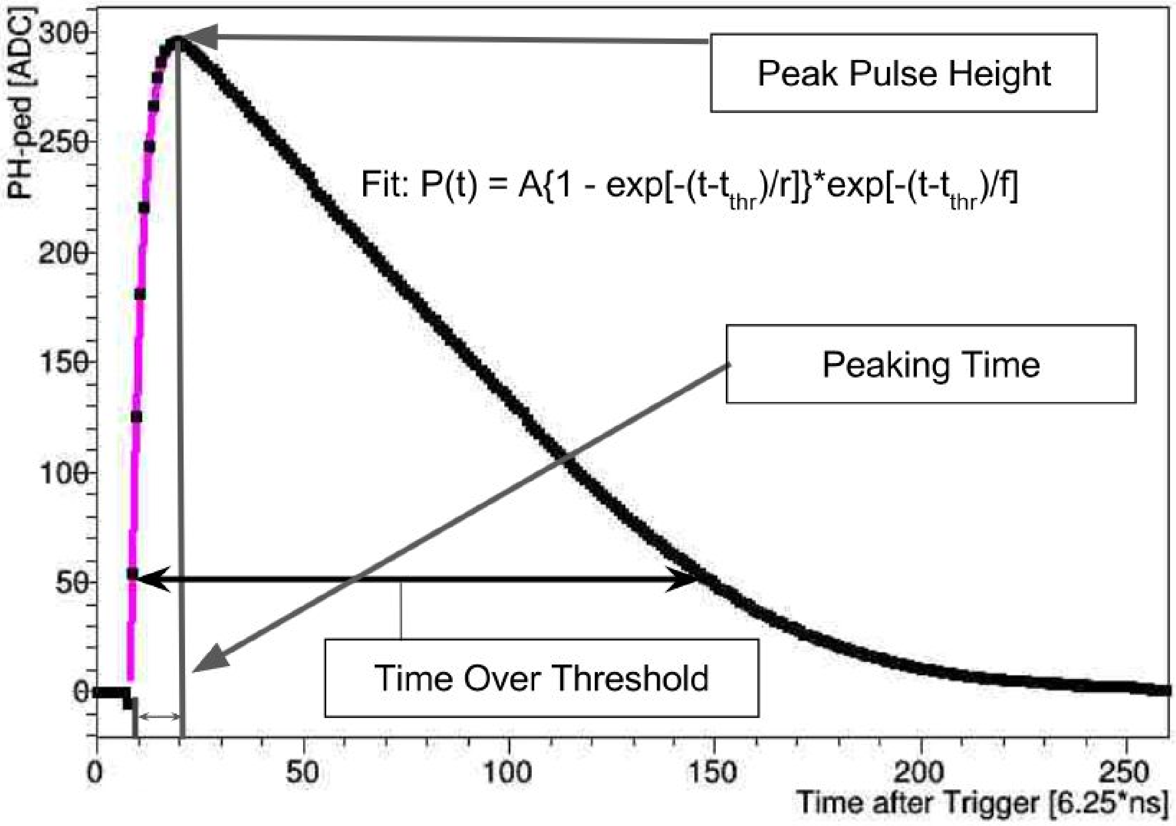

Figure 6: A fitted pulse shape with emphasis on the time over threshold, peaking time, and peak pulse height.

Parameter Variations

The analogue supply voltage (Vana), preamplifier feedback resistor voltage (Vgpr), shaper feedback resistor voltage (Vgsh) and calibration pulse were sequentially varied with all other parameters held constant and a family of pulse shapes was generated from each parameter variation. The pulse fitting program was used to obtain the peak height, peak time, and time over threshold for each variation. Finally, the dependence of these three values on a varying calibration pulse was plotted.

Results

Analogue Supply Voltage (Vana)

Figure 7 shows the analogue supply voltage varied from 1.90 V to 2.10 V.

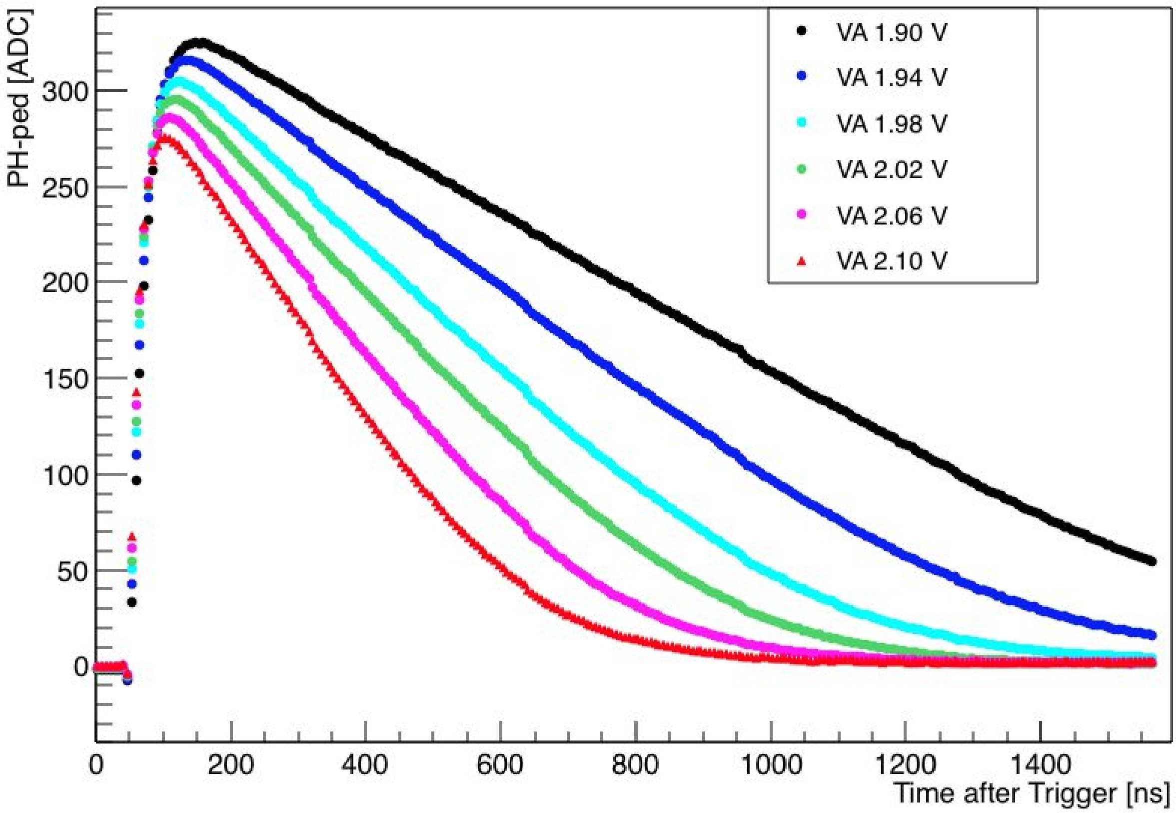

Figure 7: The calibration pulse was held at 400 mV, the preamplifier feedback resistor voltage at 900 mV, and the shaper feedback resistor voltage at 630 mV.

It is clear from the plots that at lower voltages, the both the pulse height and discharge time increase. Despite this, the peaking time does not appreciably change. This verifies the fact that the peaking time is independent of the analogue supply voltage for fixed voltages across the preamplifier and shaper, as well as a constant calibration pulse.

Preamplifier Feedback Resistor Voltage (Vgpr)

Figure 8 shows the preamplifier feedback resistor voltage varied from 500 mV to 900 mV.

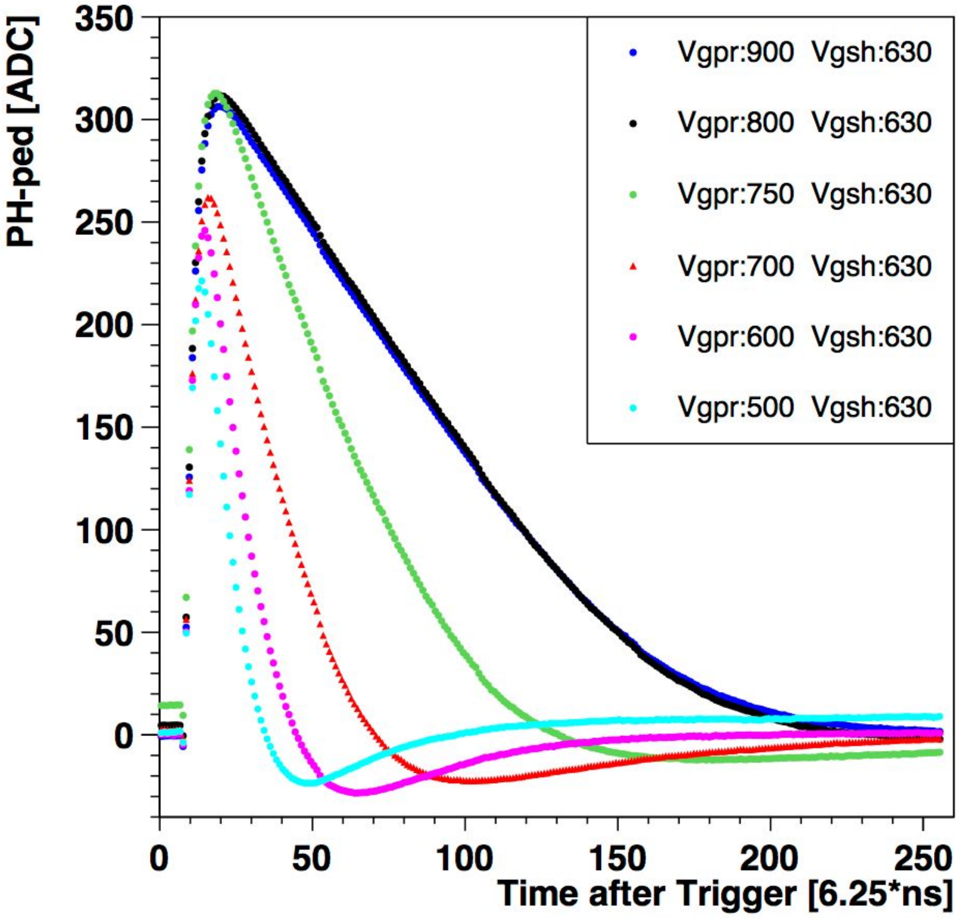

Figure 8: The calibration pulse was held at 400 mV, the shaper feedback resistor voltage was held at 630 mV, and the analogue supply voltage at 2 V.

Saturation of the preamplifier feedback voltage occurs at around 800 mV. Higher voltages don't affect the pulse shape: in the figure, the pulse shapes with 800 mV and 900 mV are nearly superimposed on one another. At lower voltages (below 700 mV) the pulse undershoots the baseline before returning to 0 mV. At higher voltages this undershoot disappears and the pulse height increases until it saturates at 800 mV. Increasing the preamplifier feedback voltage advances the peaking time from the default 35 ns to 65 ns.

Shaper Feedback Resistor Voltage (Vgsh)

Figure 9 shows the pulse shape response to the shaper feedback resistor voltage varying from 400 mV to 800 mV.

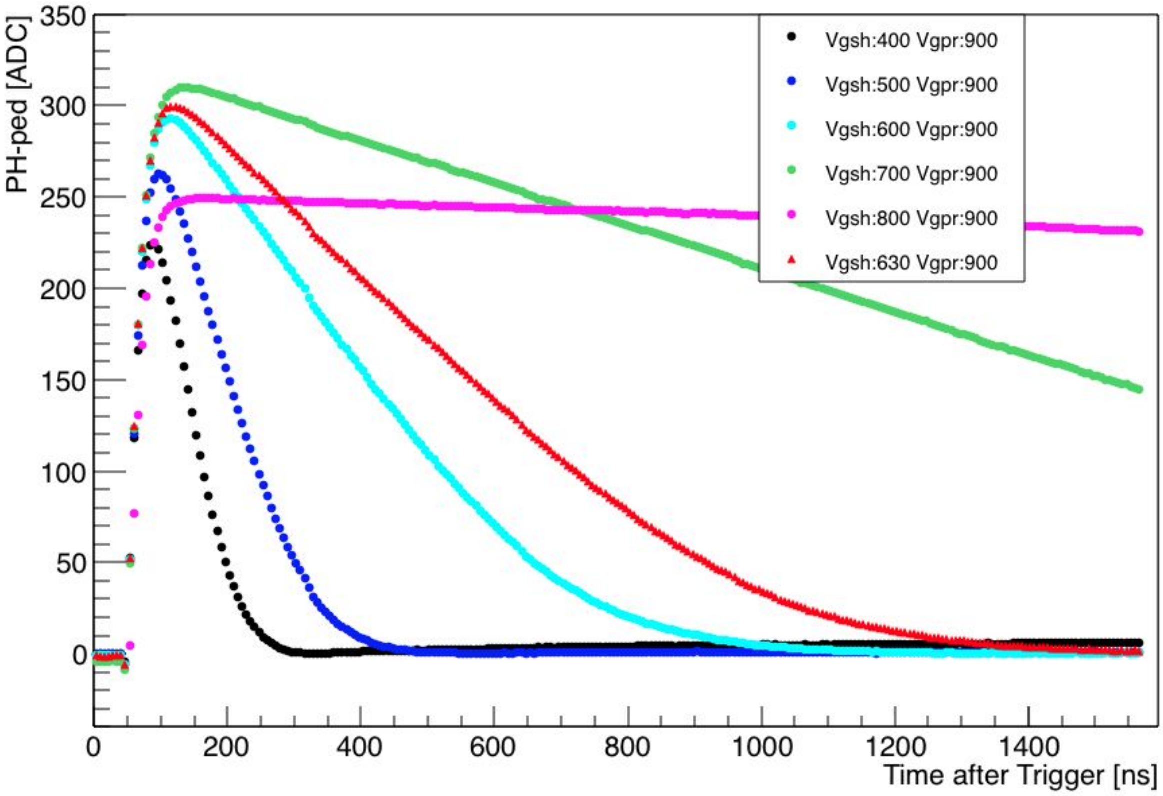

Figure 9: The calibration pulse was held at 400 mV, the preamplifier feedback resistor voltage was held at 900 mV, and the analogue supply voltage at 2 V.

In the range of 400 mV there is a massive change in the pulse shape. At low voltages (400 mV), the shaper circuit quickly restores the pulse to baseline. At high voltages (800 mV), the pulse flattens out. For X-ray sources this is ideal: a slow pulse discharge maximizes the yield due to increased integration time. At 700 mV the peaking time could be extended further to 92 ns.

Calibration Pulse Amplitude (Cal Pulse) and Correlation Plot

Figure 10 shows how varying the calibration pulse amplitude affects the pulse shape.

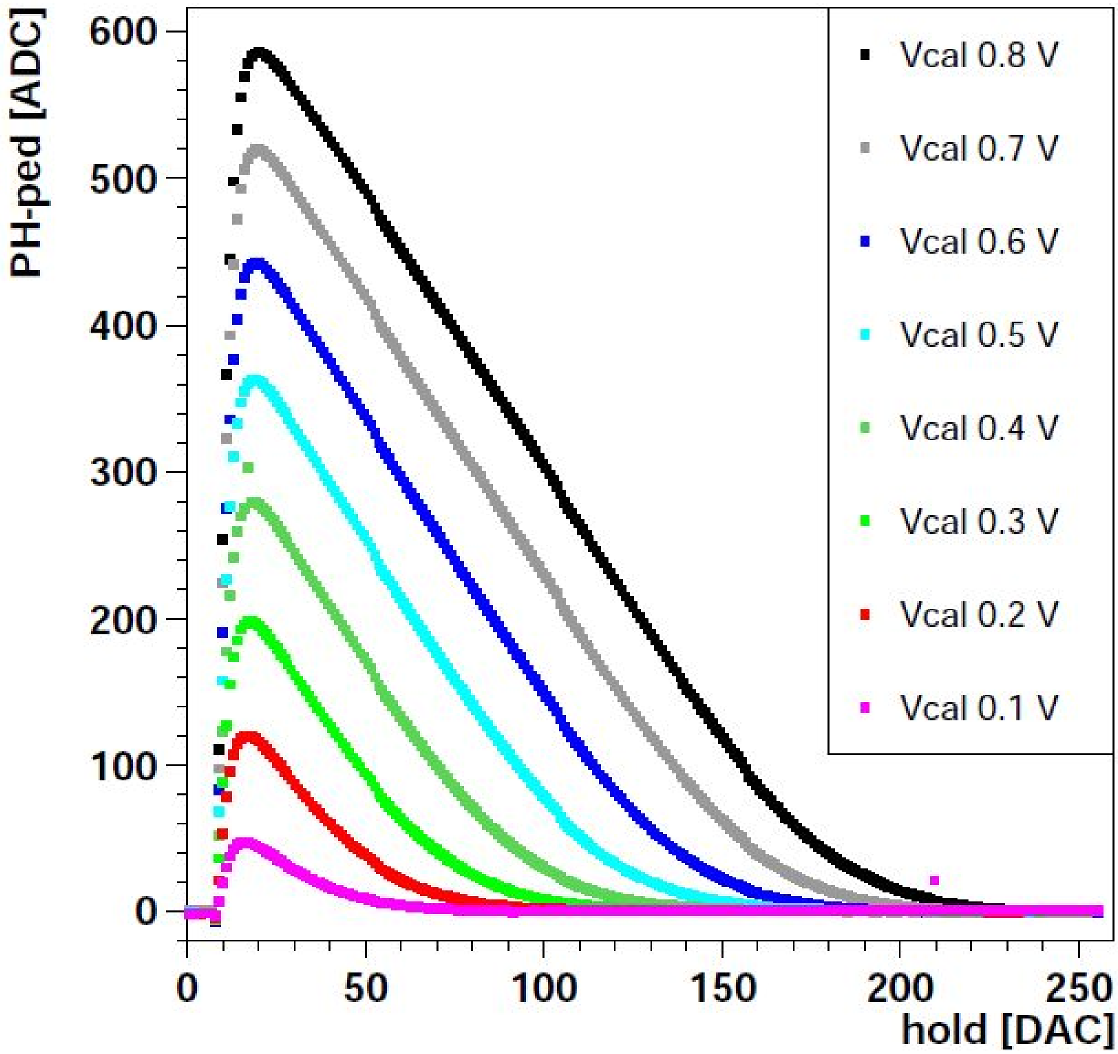

Figure 10: The preamplifier feedback resistor voltage was held at 900 mV, the shaper feedback resistor voltage was held at 630 mV, and the analogue supply voltage at 2 V. The timing units are in the DAC hold units to visualize the hold delay. To convert to nanoseconds one could multiply by 6.25.

While the peak pulse height increases with the calibration pulse in this range, the peaking time is almost constant. These features were explored over a larger range of calibration pulses and plotted along with the time over threshold for each pulse, as shown below in figure 11.

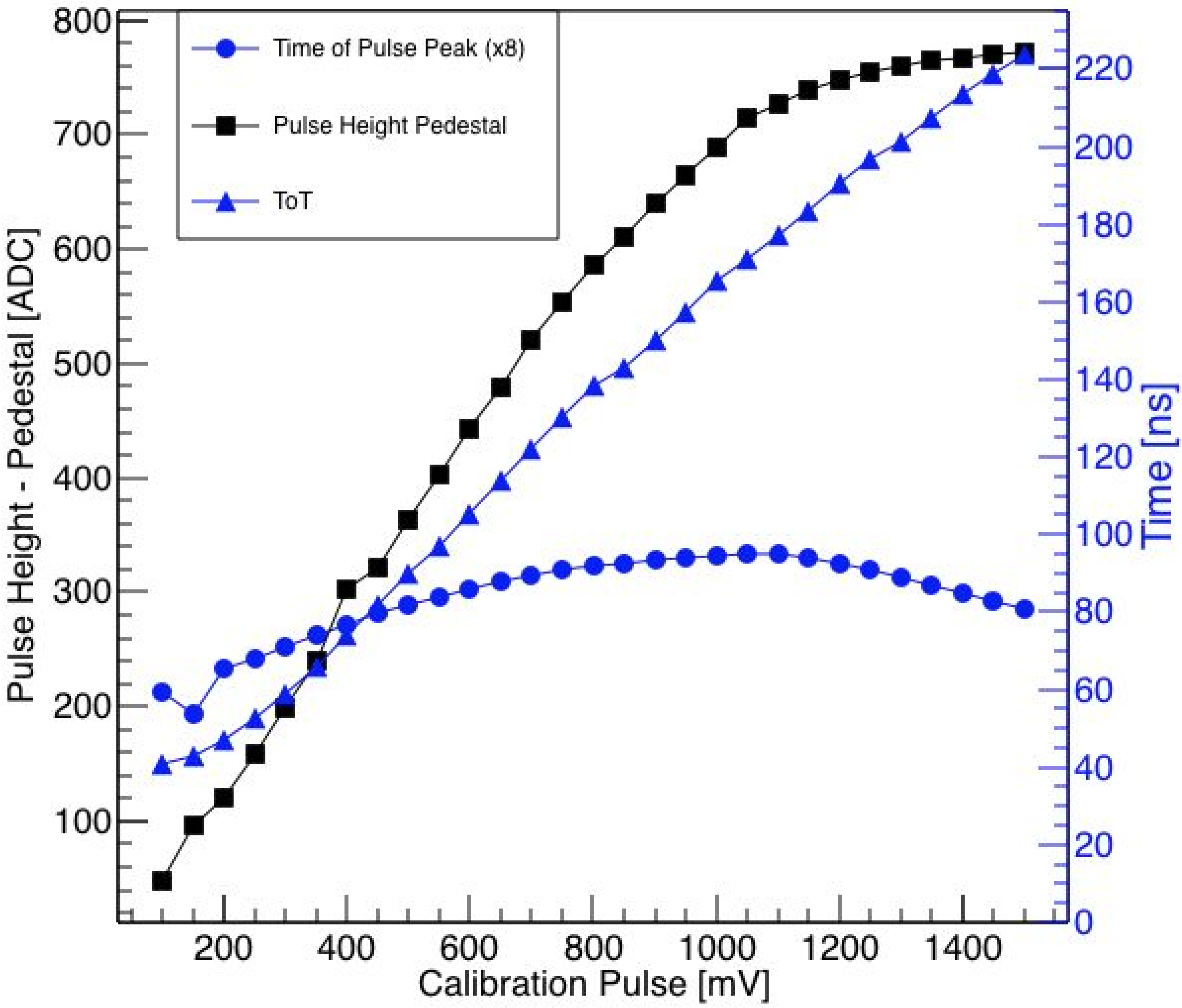

Figure 11: The preamplifier feedback resistor voltage was held at 900 mV, the shaper feedback resistor voltage was held at 630 mV, and the analogue supply voltage at 2 V. The peaking time is scaled by a factor of 8.

It can be seen that the pulse height maintains a linear form until 1 V where it begins to saturate. The time over threshold however (magnified by a factor of 8), stays linear for the entire range of 1.5 V. The time of pulse peak does not vary more than 24 ns from its average value of 67.7 ns and has a std deviation of 8.8 ns.

Conclusion

A new pixel readout chip has been taken into operation. The default settings for the ROC4SENS yield a pulse peaking time of 35 ns. By adjusting the preamplifier from 630 mV to 900 mV and the shaper feedback resistor voltage from 600 mV to 630 mV, the peaking time can be extended to 92 ns. This can be crucial for a test beam with a 40 ns trigger, which is roughly the delay of the DESY test beam. If the trigger takes a longer time than the peaking time, data acquisition will begin after the pulse peak height is reached and an incomplete pulse signal will be measured. The analogue supply voltage simultaneously affects the rise time and fall time and so should be kept constant. Changing the calibration pulse amplitude from 100 mV to 1500 mV was shown to not vary the peaking time by more than 24 ns from the average of 67.7 ns. Finally, while the pulse height was demonstrated to saturate past a 900 mV calibration pulse, the time over threshold for a pulse shape was shown to maintain a linear relationship with the calibration pulse for values of at least 1.5 V.

Acknowledgements

1. Designers at PSI: Roland Horisberger, Hans-Christian Kaestli, Beat Meier, Tilman Rohe, Stefan Wiederkehr
2. Wiederkehr, S. (2015).PSI-ROC4SENS: A pixel-ROC for sensor tests [pdf]. Retrieved from https://indico.cern.ch/event/456679/sessions/100060/#20151204
3. Source of Figure 1: http://cms.web.cern.ch/news/silicon-pixels

Thanks

I would like to thank my two supervisors Daniel Pitzl and Paul Shuetze for incessantly helping me with my project, going out of their way to be an open source for information and advice, and creating an environment at DESY such that every morning I was excited to get to work.