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Diode readout electronics for beam intensity and position monitors for FELs

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Abstract. LCLS uses Intensity-Position Monitors (IPM) to measure intensity and position of the FEL x-ray pulses. The primary beam passes through a silicon nitride film and four diodes, arranged in quadrants, detect the backscattered x-ray photons. The position is derived from the relative intensity of the four diodes, while the sum provides beam intensity information. In contrast to traditional synchrotron beam monitors, where diodes measure a DC current signal, the LCLS beam monitors have to cope with the pulsed nature of the FEL, which requires a large single shot dynamic range. A key component of these beam monitors is the readout electronics. The first generation of beam monitors showed some limitations. A new scheme with upgraded electronics, firmware and software was implemented resulting in a more robust and reliable measuring tool.

1. Introduction

LCLS [1] uses Intensity-Position Monitors (IPM) to measure intensity and position of the FEL x-ray pulses [2][3]. The primary beam passes through a silicon nitride film and four photodiodes, arranged in quadrants, detect the backscattered x-ray photons. The position is derived from the relative intensity of the four diodes, while the sum provides beam intensity information. In contrast to traditional synchrotron beam monitors where diodes measure a DC current signal, the LCLS beam monitors have to cope with the pulsed nature of the FEL. This requires dedicated pulse processing electronics, called Intensity Position Intensity Monitor Board (IPIMB), which has to quantify a large dynamic range of charge signals on a shot-by-shot basis. The original design and the modifications implemented in the upgraded version are presented and discussed in this manuscript.

2. Design

The first generation IPIMB electronics for reading out these diodes was deployed in 2010 and used a charge sensitive amplifier followed by a RCCR shaper. The charge sensitive amplifier is AC coupled and the photodiode bias voltage is applied over a large biasing resistor. Due to the known arrival time of the FEL pulse, the time when the waveform produced by the RCCR shaper reaches its maximum is also known. Therefore the amplitude information can be achieved by sampling the signal amplitude with a single ADC sample at this time, without an additional peak stretcher. Baseline fluctuations at the output of the filter, generated for instance by fluctuations of the FEL beam power, are corrected by taking eight samples before the FEL pulse and subtracting their average from the sampled peak. After each FEL pulse the resistive bias network has to recharge the diode. This results in a slowly rising

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voltage over the diode whose steepness depends on the average beam energy within the time constant of the bias network. The rising voltage in turn offsets the output of the simple RCCR shaper causing additional systematic variations of the baseline. In addition, changes in environmental conditions, such as temperature and stray light, affect the diode properties.
Various mechanisms limit the performance of this analog processing scheme. As the amount of charge detected should ideally cover up to five orders of magnitude to make the device a usable diagnostic under real experimental conditions, the rise time and shape of the signal at the diode and after the preamplifier varies considerably. The RCCR shaper imposes a compromise between the practical shaping time and the sensitivity to rise time variations. Furthermore, the signals are affected by pickup over the relative long leads needed to connect the diodes, that are mounted inside a vacuum chamber on the beamline, to the electronics in air. This pickup is often a combination of various but specific frequencies. The RCCR filter attenuates high frequency noise but does not suppress selected frequencies. As only one output value is measured, it can be very difficult to identify the origin of a possible pickup from beamline components such as a vacuum pump or motorized stage.

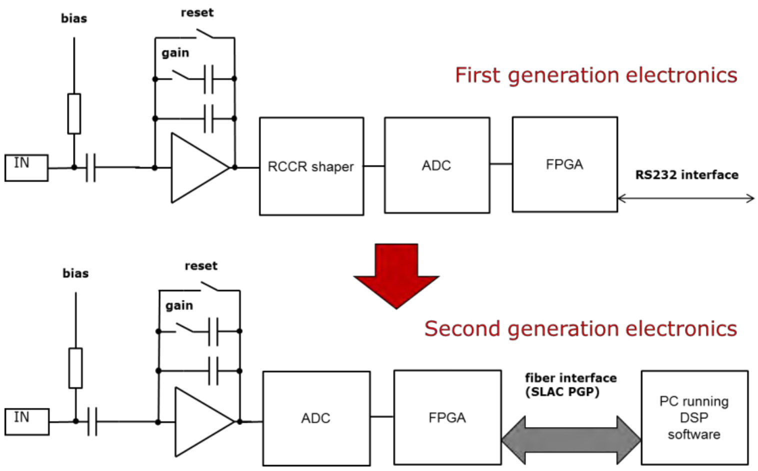

Figure 1. Block diagrams of the first (top) and second (bottom) generation electronics for photodiode readout at LCLS. The second generation replaces the fixed RCCR shaper with software-based digital signal processing of the sampled waveform.

The original design was modified by removing the shaper and instead sampling the waveform at the output of the charge sensitive amplifier continuously. All waveform samples are sent to the data acquisition system via a fiber optical high speed link (SLAC Pretty-Good-Protocol, PGP). The sampled waveform can then be shaped in real-time applying digital signal processing methods available within the online monitoring software. The software is capable of waveform fitting or Finite Impulse Response (FIR) filtering. The block diagrams of the two systems, original and modified, are shown in figure 1.
Figure 2 (top) shows a representative waveform response of an x-ray photodiode to a photon pulse. It is worth mentioning that the rise time of the signal is slightly dependent on the amplitude and gain settings. This can be attributed mainly to the limited slew rate and current capability of the op-amp used in the charge sensitive amplifier. In fact, the large instantaneous signals on the diode impose challenging requirements for the front-end amplifier. To be less sensitive to these variations and suppress baseline fluctuations, we used a simple FIR trapezoidal filter with flat top. This filter has also the advantage of exhibiting distinct zeros in the frequency transfer function: specific pickup frequencies can be supressed by choosing the right averaging length. Given a dataset of example waveforms, an optimised filter can be synthesised to maximise the signal-to-noise ratio. Different filters optimised for different operation regimes (low, medium, high signal) could also be considered. The FIR filter coefficients can be loaded into the online monitoring software and the waveform

processed in real-time for all the LCLS pulses (120 events per second). The lower half of figure 2 shows an example of the resulting waveform after filtering. The software can then use the peak of the filtered waveform as a scalar value of the diode signal for further processing.

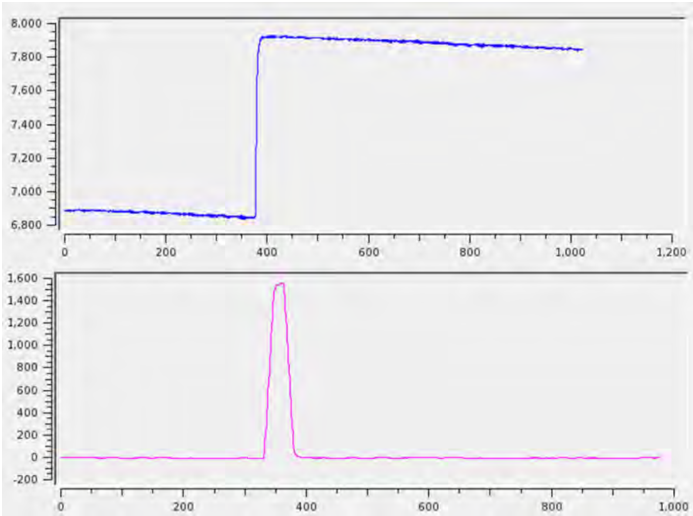

Figure 2. Example of a captured waveform from a photodiode (top) as displayed in the online monitoring software. The software applies an arbitrary FIR filter to the waveform in real-time (bottom). The peak of this filtered waveform can be used as a scalar value representing the diode signal for further processing.

Having access to the amplifier output waveform in real-time from the online monitor helps considerably with debugging an experimental setup: parameters such as timing, signal amplitude and the recovery time from the diode bias network can be immediately seen. Furthermore the waveform can be analysed for specific pickup frequencies and the experimental setup investigated for possible noise sources accordingly. This new system, Intensity Monitor with SLAC PGP (IMP), has 4 channels and is designed to readout signals from photodiodes or avalanche photodiodes. The calculated dynamic range of this electronics is up to 3 million photons with a noise of 25 photons at 8 keV photon energy when used with an x-ray photodiode. As shown in the following section, the IMP can also be combined with a commercial Silicon Drift Detector (SDD).

3. Measurements and Conclusions

Measurements were performed at the CXI instrument [4] at LCLS using pink SASE beam at 9 keV. The primary beam hit a sample (100 µm glass with 50 nm gold coating) producing roughly uniform scattering and a small fraction of the photons from the primary beam were impinging on the diode. Figure 3 shows the IMP box and the commercial x-ray photodiode used for this test.

In figure 4, as a proof of concept, the signal measured with the diode is plotted against the FEL beam energy measured with the LCLS gas detector [5]. The x-axis spans the entire range of the FEL pulse energy used during this measurement.

To demonstrate the flexibility of the approach we connected the IMP electronics to a commercial SDD which includes a preamplifier with pulsed reset. The captured waveforms were processed with a trapezoidal FIR filter very similar to the one used for the photodiode. The resulting spectrum, a histogram of the measured signal amplitudes over many FEL shots, is shown in figure 5. The achieved energy resolution is 180 eV for the Iron K_α line and 230 eV for the simultaneous pileup of two Iron K_α photons. These results show that this new system (IMP) addresses the issues of the previous version (IPIMB) and is suitable for a variety of applications.

Figure 3. Photograph of the prototype Intensity Monitor with PGP (IMP) to readout photodiodes (left). The photograph on the right side show the commercial x-ray photodiode used for the measurements. A sheet of 30 µm Kapton is glued in front of the diode to block optical light.

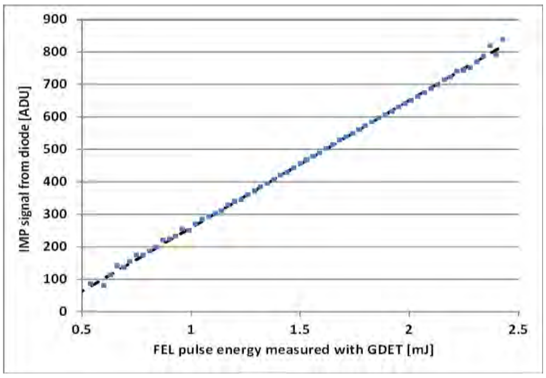

Figure 4. Diode signal vs. LCLS beam pulse energy measured with a gas detector. The measurement was performed at the CXI instrument of LCLS with pink SASE beam at 9 keV. The x-axis spans the full pulse energy range of the FEL used during this measurement.

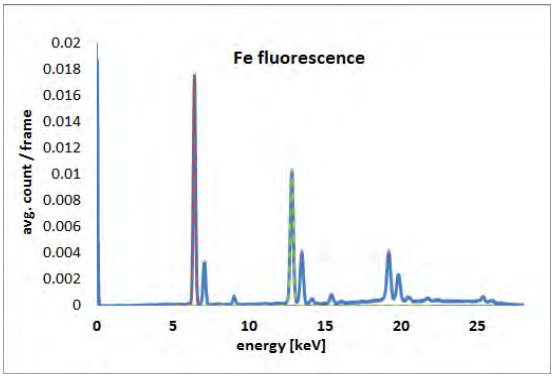

Figure 5. Iron fluorescence spectrum measured with the IMP prototype connected to an SDD. For single photon events the Iron K_α, K_β and the primary beam energy of 9 keV can be identified. Further two, three and four photon pileup events can be seen in the spectrum. The measurement reached 180 eV energy resolution on the single photon Iron K_α line.

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