Development of One-Coordinate Detector for Diffraction Experiments at a SynchrotronRadiation Beam

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***Abstract*—One-coordinate detector for diffraction experiments at a synchrotron radiation beam is being developed in the Budker Institute of Nuclear Physics for future Synchrotron Radiation Facility SKIF. In order to reach spatial resolution better than 100 µm for photons of 3-30 keV energy range the detector has to use silicon or gallium arsenide microstrip sensor with specialized integration circuits for signal detection. The first version of the new detector prototype had GaAs sensor with 50 µm strip pitch. The new detector SciCODE has silicon microstrip sensor with strip pitch of 50 µm as a detection element. The detector works in direct photon counting mode, provides spatial resolution better than 100 µm and counting rate capability of 1 MHz in each registration channel. A prototype of specialized integration circuit SciCODE8 is developed for signal detection in the first prototype. SciCODE8 has 8 registration channels which can count individual photons and sort them according to their energy.**

Keywords—diffraction experiments, synchrotron radiation, coordinate detector, photon counting mode, application specific integration circuit

I. Introduction

Synchrotron radiation (SR) is a unique instrument for studies of dynamics of fast physical or chemical processes. Short flashes of radiation generated by electron bunches in an SR source allow to perform measurements with high temporal and spatial resolution using an appropriate detector. The best results in such experiments can be reached with multi-channel coordinate detectors based on semiconductor sensors with strip or pixel structure as a sensitive element, where each channel operates either in integrating or counting mode [1-9].

Direct photon counting regime is used for the studies of relatively slow processes. Signals from individual photons are registered in this regime. This feature as well as the possibility to sort photons according to their energy opens the opportunity for getting more detailed information about the processes under study.

The detectors for the experiments at SR beams are developed and used at VEPP-3 and VEPP-4 storage rings in the Budker INP SB RAS for more than 20 years [10-11]. In particular, the OD-3M detector based on multi-wire proportional chamber technology, has 64 physical and 3300 calculated channels on their basis. OD-3M has spatial resolution of 180 µm for photons of 8 keV. Two such detectors are in operation at the Siberian Synchrotron and Teraherz Radiation Centre in Budker INP SB RAS [12].

The new detector SciCODE, based on semiconductor microstrip sensor working in photon counting mode is developed in BINP SB RAS at present. The detector will provide spatial resolution better than 100 µm, frame rate more than 10 kHz and rate capability up to 1 MHz/channel, that is necessary to reach high speed of recording of the measurements.

II. The Structure and Main Detector Parameters

The structure of the detector SciCODE is shown schematically in Fig.1. The detector consists of gallium arsenide (GaAs) or silicon microstrip sensor with strip pitch of 50 µm. The GaAs sensor [13-15] was provided by the Centre “Prospective technologies in microelectronics” of Tomsk State University. The silicon sensor was manufactured by Hamamatsu Photonics company. Each sensor strip is connected to the registration channel of the application specific integration circuit (ASIC) SciCODE8

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developed in BINP SB RAS. The registration ASIC is controlled by FPGA that also provides the data readout [16]. The detector components are shown in Fig.2.

The structure of the registration channel of the SciCODE8 ASIC is shown in Fig.3. It consists of the charge-sensitive and shaping amplifier with charge amplification of 400 mV/fC, four comparators with controlled thresholds (global and local), four 5-bit digital-to-analog converters (DAC) for the adjustment of individual channel thresholds and four 8-bit scalers counting the number of triggering of each comparator within the exposure time of one frame. After the end of frame exposure, the data are copied from the scalers to the output shift register and then recorded in the external memory.

The registration channels have two types of controlled thresholds: global and individual. The global thresholds are adjusted with external 6-bit DACs. The range of adjustment of the global thresholds is 0 ÷ 1.5 fC and the adjustment range of the individual thresholds is 0 ÷ 0.2 fC. The voltages corresponding to the global thresholds are supplied from the external DACs to the comparators of all ASICs. More precise adjustment of the thresholds of each channel is provided by the individual DACs of each channel. The global thresholds are used to select up to four energy ranges in the registered photon flux. The individual thresholds serve to equalize the counting efficiency of the channels.

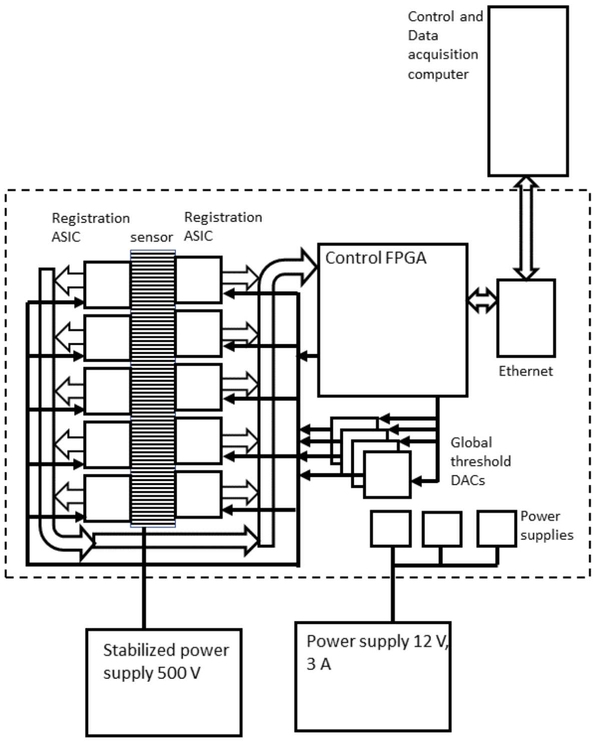
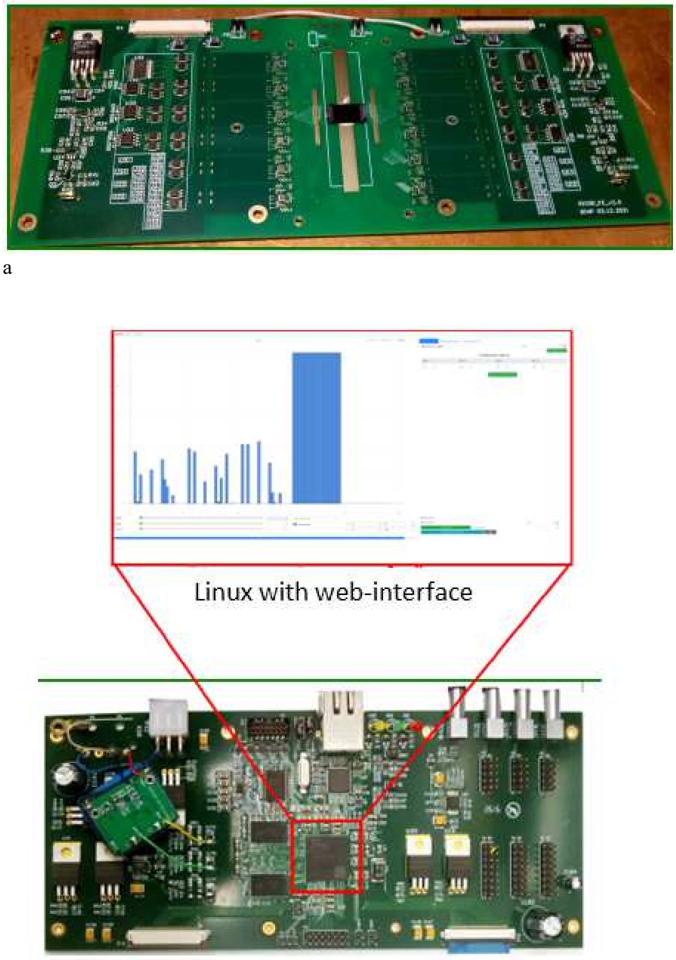


Fig.1 Flow-chart of the SciCODE detector.

III. Results of the First Tests of the SciCODE Prototype

The results of the first tests of SciCODE8 ASIC parameters are shown in Fig.4,5. Calibration signal was fed to the inputs of the ASIC channels and the output signal of the shaping amplifier of one channel is shown in Fig.4. The signal amplitude and shape correspond very well to the results of the simulation and shaping time is close to 300 ns.



a

b

Fig.2. SciCODE detector components: a) registration board with GaAs sensor in the centre and 16 SciCODE8 ASICs; b) motherboard with FPGA and sysem-on-chip.

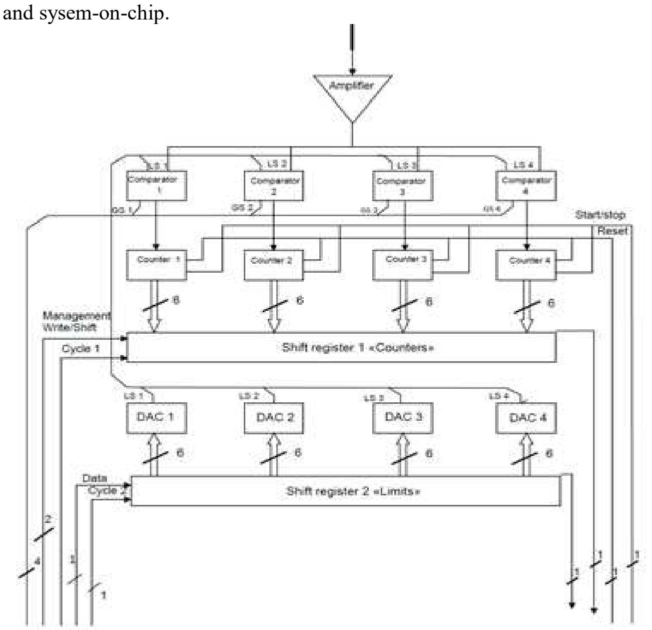


Fig.3. Schematic structure of the registration channel of the SciCODE8 ASIC.

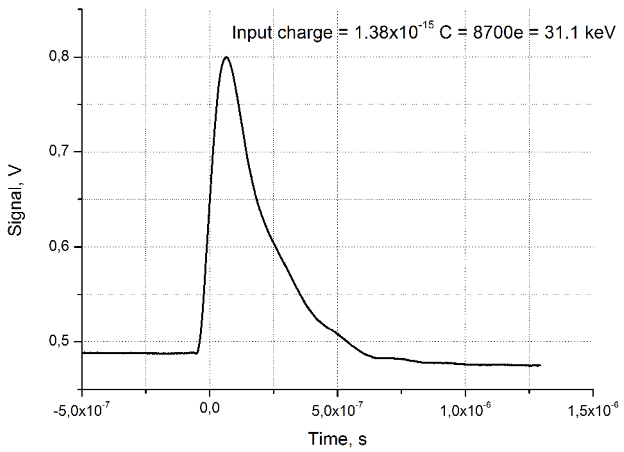


Fig.4. Results of the tests with electronic calibration: signal shape at the output of the shaping amplifier.

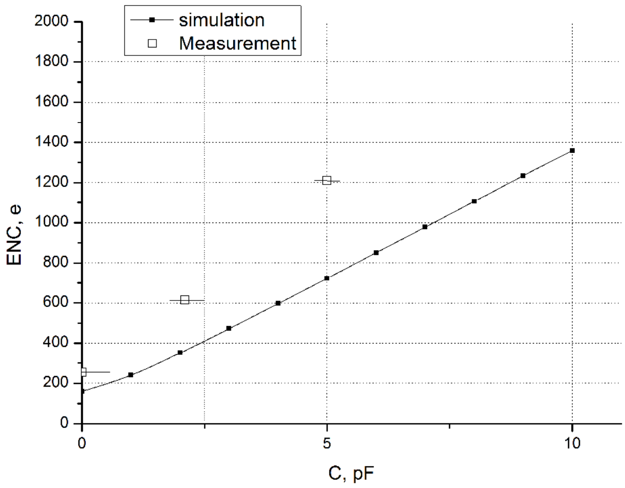


Fig.5. Dependence of equivalent noise charge on input capacitance: measurement and simulation.

Dependence of equivalent noise charge on input capacitance is shown in Fig.5. The noise value at zero input capacitance is close to the simulation result. However, the results of the measurements with capacitance not equal to zero are significantly higher than the result of the simulation. It was found that the reason of high noise is poor filtration of low-frequency noise at the reference voltage source. This feature will be corrected in the next version of the ASIC.

Dependence of count rate on the threshold is an important characteristic of registration channel of the ASIC. Due to its shape, it is often called "S-curve". The count rate is equal to the frequency of input signal in the range of thresholds between the noise level and the signal amplitude. When the threshold becomes close to the signal amplitude, the count rate starts to drop and decreases to zero level, while the threshold exceeds the signal. S-curves for four channels measured with electronic calibration are shown in Fig.6. The charge injected to the inputs of the channels is equal to ~2900 electrons that is close to the charge deposited by 10.4 keV photon in silicon. The S-curves in Fig.6 are obtained by gradually increasing the global threshold. From the figure one can see that the individual thresholds of channels 3, 5 and 6 are equal to each other, while the individual threshold of channel 4 is ~10% higher or amplification of this channel is about 10% lower. The derivative of S-curve shows pulse height spectrum of the input pulses (Fig.7). This characteristic can be used to estimate the energy resolution of the detector. Electronic calibration shows the lower limit of the energy resolution that is determined by the amplifier noise. For the current conditions it is close to 1.3 keV (FWHM) for 10.4 keV equivalent energy deposition.

IV. Conclusions

The eight-channel prototype of the registration ASIC for the SciCODE detector is developed and tested. The 96-channel prototype of one-coordinate X-ray detector is assembled, firmware and software that allow to perform the first tests are designed and the measurements of the main parameters of the electronics are performed. In close future we plan to perform the measurements of the main characteristics of the detector prototype at the SR beam. The full-size 64-channel registration ASIC is designed and submitted for production.

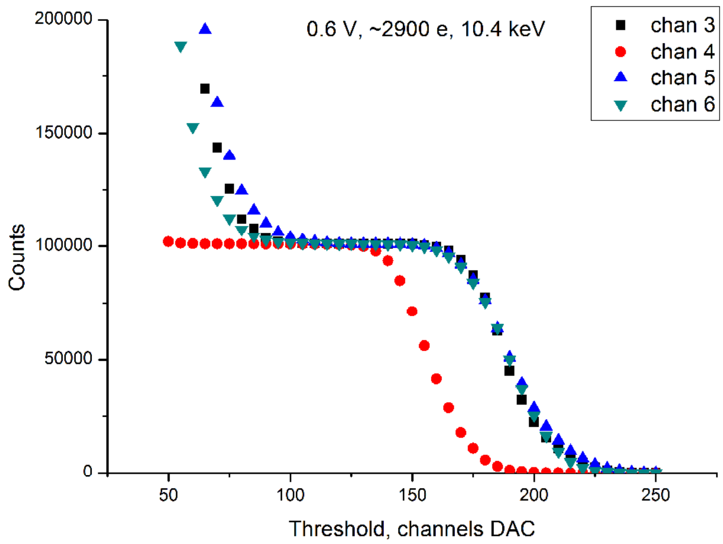


Fig.6. S-curves of four channels.

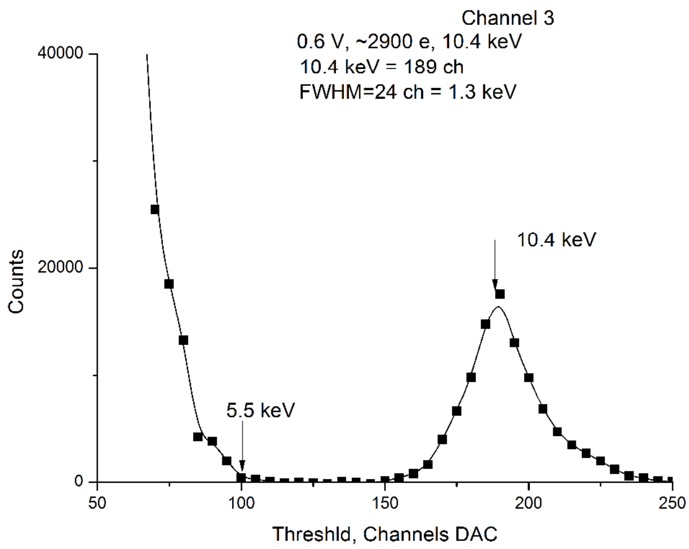


Fig.7. Spectrum of calibration signals, calculated from S-curve.

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