Two-dimensional position-sensitive spectrometer for registration of ionizing radiation

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Abstract. A new two-coordinate position-sensitive spectrometer for the measurements of spatial and energy distribution of ionizing particles was developed. The sensitive elements of the device are two orthogonal 64 strip semiconductor detectors whose signals are read out by two Application-Specific Integrated Circuits (ASIC) IDE1140 comprising 64 spectrometric channels each. Control, pre-processing data acquisition and transfer to a computer are carried out using FPGA circuit EP3C16Q240. The main spectrometer characteristics obtained in the measurements are: equivalent noise charge of 0.7 fC and integral nonlinearity is below 1% in the range from 5 to 160 fC.

1. Introduction
The progress of astrophysics, nuclear and high energy physics is mainly related to the improvement of position-sensitive systems including those with high spatial and energy resolution based on strip detectors [1]. The systems successfully used at Large Hadron Collider in CERN [2] and in the experiments with radioactive beams on the DRIBs-III complex at Joint Institute for Nuclear Research, Dubna, [3] are perspective for implementation at the international accelerator facility FAIR at GSI (Darmstadt, Germany) [4]. The Ioffe Institute is participating in various national and international projects, performing investigations and developments of silicon strip detectors and electronic systems for them [5].

2. Spectrometer schematic
The block diagram of the two-dimensional position-sensitive spectrometer is shown in figure 1. Two single-sided semiconductor detectors containing 64 strips with a thickness of 150 µm are installed one behind another and tilted at 90° relative to each other. One detector (vertical strips) allows to define the X-coordinate of the detected particle interaction point and another (horizontal strips) to register the Y-coordinate. The signals from all 128 strips are readout by two Application-Specific Integrated Circuits (ASICs) IDE1140. Each ASIC includes an array of 64 spectrometric channels, an analog multiplexer, the registers and logic elements (figure 2). An individual spectrometric channel contains a
charge-sensitive preamplifier (PA), a shaping amplifier (Shaper) and a Sample & Hold unit. All 64 Sample & Hold units are triggered by a common external signal (HOLD) which is generated by Field-Programmable Gate Array (FPGA) after receiving an External Trigger signal. To sample the amplitude of the shaped signal, the HOLD signal is delayed in FPGA for triggering the circuit at the peak time of the shaped signal. While HOLD signal is high, FPGA sends 64 clock pulses to the multiplexer register (MUX), providing sequential readout of signal values held in the Sample & Hold circuits. Then, the picked-up values are amplified in IDE1140 by an internal differential amplifier (DA) and a two-stage separate amplifier (Amp). Finally, all signals are digitized by Analog-to-Digital Converters (ADC), one in each X and Y channels. The data received from ADCs are pre-processed by the same FPGA and stored in the internal memory for future transfer to a computer (PC) via an USB-interface. Since levels of control signals in IDE1140 differs from that used in FPGA, the level shifting unit is implemented.

Figure 1. The block diagram of the spectrometer. Abbreviations used here are explained in the text.

Figure 2. Structural schematic of IDE1140 demonstrating the signal shapes in the critical points of the chip. Abbreviations used here are explained in the text.

The developed software controls the parameter settings for the signals providing the IDE1140 operation, the signals readout, data processing and presentation of the results on the computer. It allows also the amplitude discrimination for differentiating between physical events and noise, which
can overload the data acquisition system. The software ensures spectrometer operation in several modes: two-dimensional, one-dimensional and oscilloscopic mode. In the two-dimensional mode, the trigger signal initiates memorizing the signal amplitude in all channels of the X and Y strip detectors simultaneously. The following data treatment aimed at finding the correlations between the signals on X and Y strip arrays gives the prompt 2D distributions of deposited charge in the detectors and the 2D profile of the beam intensity. Using the detectors with different thicknesses, the detailed data treatment makes it possible to resolve between the particles with different mass (so-called 2D position sensitive telescopic measurements). In the one-dimensional mode, search for the data correlation between two strip detectors is not anticipated in the program and therefore the measurements are carried out as two 1D independent orthogonal scans of the beam intensity.

The oscilloscopic mode is used for a direct observation of signals from the IDE1140. It gives the signal waveforms of two independent channels, one from each ASIC. This mode is effective for testing the channels operation as well as for adjusting the HOLD signal delay to measure the signal amplitude at the signal peak time exactly. The mode makes it possible to observe the so-called “array signal” as an output levels multiplexing, i.e. a sequence of output signals along the strip array with each level equal the energy deposited in the individual strips of the detector at the moment of HOLD signal arrival.

3. Mechanical structure of spectrometer

The spectrometer is built to detect ionizing particles at vacuum conditions inside experimental chambers. Its mechanical structure is divided into two parts operating in vacuum and atmosphere. The construction of vacuum part is optimized to transfer the heat dissipated in electronic units to the walls of vacuum chamber. The main structure of this part is a monolithic metal frame precisely fixed on the vacuum flange. The frame maintains two detector boards which are fixed on the opposite frame sides. The construction potentially allows improvement of the thermal contact by application of thermal conductive vacuum grease between the PCB and the frame.

The detector boards contain strip detectors, pitch adapters, ASICs and the first stage of the external amplifier. The construction enables one to adjust the position of the detectors to the axis of ion beam. The connection of strips with the pitch adapter and then with IDE1140 chip is performed by ultrasonic wire bonding technology. To provide the signal transfer through the flange, a vacuum feed-through with multiple pins is used.

The components of the second stage of signal amplification, ADCs, FPGA and the accessory utility circuits are mounted on the board and attached to the flat metal frame rigidly fixed to the flange. All signal inputs and outputs of the spectrometer and power connector via standard AC/DC compact adapter are located on a front panel. The outer metal casing on the atmospheric side and the front panel protect the spectrometer from external mechanical and electromagnetic impacts.

4. Main characteristics

Figure 3 demonstrates the signals recorded in the critical points of spectrometer. They characterize operation of the IDE1140 chip and are important for monitoring the chip operation. The signals can be taken from the connectors at the front panel or observed on the computer. The presented signals are screenshots for the spectrometer operation in the oscilloscopic mode: a) the shape of “quasi-Gaussian” signal at the output IDE1140 Shaper (rise time – 6.5 µs, fall time – 30 µs), b) the fragment of the “array signal” containing the sequential readout of 12 channels of IDE1140 chip.
Figure 3. Output signals from IDE1140 at oscilloscopic mode: a) pulse at the Shaper output of IDE1140 chip (rise time – 6.5 µs, fall time – 30 µs), b) fragment of the “array signal” containing the sequential readout of 12 pcs from 64 channels of IDE1140 chip.

The obtained characteristics of the spectrometer are listed below.

- Dynamic range is from 5 to 250 fC.
- Integral nonlinearity is lower than 1% in the range of 5 to 160 fC.
- Equivalent noise charge is 0.7 fC.
- Conversion factor is 4.4 ADC channel per fC in the range of 5 to 160 fC.
- Readout time of two IDE1140 is 64 µs.
- Power supply is 12 V/300 mA.
5. Conclusion
The described spectrometer allows simultaneous registration and spectrometry of radiations by various sensors; however, full potential of the design is realized with silicon microstrip detectors. This type of sensors is optimal for the signal readout and integration with modern multichannel front-end microelectronic devices. The described design was tested in operation with silicon microstrip and strip detectors with the sensitive region area ranging from tens of mm$^2$ to tens of cm$^2$.

References
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