Application of the multichannel front-end chip for SiPM-based gamma detector

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Abstract. A prototype of a multichannel application specific integrated circuit (ASIC) analog front-end chip was recently developed at the Department of Microelectronics in MEPhI for SiPM-based applications [1]. The chip designed as an analog front-end for the detectors using scintillation crystals NaI(Tl) or CsI(Tl) coupled with a SiPM photosensor. The chip can be used to build multichannel systems in such fields as nuclear science, medical imaging and homeland security.

1. Introduction

Silicon Photomultiplier (SiPM) is a photosensor consisting of a matrix of reverse-biased photodiodes operating in the Geiger discharge mode. SiPM's attractive features are a high gain and photodetection efficiency, low operating voltage, insensitivity to magnetic fields and a small size. SiPMs coupled to a scintillator crystals can be used to create a compact and robust gamma-spectrometer and is a very attractive choice for creation of high granularity multichannel systems, especially in the field of the nuclear medicine. However, development of such systems, which are usually based on NaI(Tl) or CsI(Tl) scintillation crystals, is hold back by the lack of a front-end multichannel electronics designed to operate with those "slow" (microsecond time scale) scintillators.

A prototype of a multichannel application specific integrated circuit (ASIC) analog front-end chip was recently designed at the Department of Microelectronics in MEPhI for SiPM-based applications and fabricated at XFAB Foundry with XH035 technology [1]. The chip designed to be used as an analog front-end in multichannel systems utilizing NaI(Tl) or CsI(Tl) coupled with a SiPM photosensor.

2. Chip structure, evaluation board and software

For performance comparison the prototype chip includes two type of channels: one type for processing a current signal (low input impedance preamplifier) and another type for a voltage signal (high input impedance preamplifier). Each channel contains a code-controlled preamplifier, a controlled integrator, two code-controlled amplifier-shapers, a peak-detector, an amplitude discriminator, two timers, an analog output buffer with a level-shift module, a logical output and a controlling circuitry. The chip is configured by loading data into the block of control registers via a serial interface. Simplified block diagram of the chip shown in Figure 1. The detailed description of the prototype can be found in [1].
To conduct test measurement an evaluation board was designed and build and a LABVIEW control application was developed.

The evaluation board provides power for the prototype chip, connectors for both analog and control signals and a communication port to a control computer.

The control software developed as a LABVIEW application. Its screen-shots are shown in Figure 2 and Figure 3. The control software does the following:

- Loads configuration data into the chip setting all parameters;
- Shows current status of all main structural blocks of the chip;
- Reads out data from an external ADC that can be mounted on the evaluation board and represent the data graphically.

The evaluation board provides power for the prototype chip, connectors for both analog and control signals and a communication port to a control computer.

The scheme of the experimental setup is shown in Figure 4. The experimental setup consists of the NaI(Tl) scintillation crystal (manufactured by firm "Crystal", Russia [3]) optically coupled to the 2x2 SiPM matrix (a part of the larger matrix), the chip evaluation board (Figure 5), a digital oscilloscope LeCroy WR620zi used as a DAQ system and power supplies. The size of the NaI(Tl) crystal is ø10x10 mm². The SiPM matrix was assembled using SiPM type KETEK PM6660 (SiPM active area size 6x6mm², pixel size 60x60 μm²) [2].
The same bias voltage is applied for all 4 SiPM; each SiPM has its own RC filter (R1, C2 and so on) and 4 SiPM outputs were joined together to have a common output signal readout from R2. SiPM output signal is splitted in two ways: one is connected to the LeCroy WR620zi oscilloscope and used as a trigger signal, and the other fed to the prototype chip input type A - low input impedance type; the output of the prototype chip is connected to another oscilloscope input. The chip is configured to utilize a build-in peak-detector, so the output signal has an extended flat top.

During data taking for every trigger signal the amplitude mean values are measured in three predefined time-windows - one window where the signal is expected and two other separate windows set before the signal window for a base-line measurements. The measured values are stored on the event-by-event basis for offline processing.

Data were collected for a number of radioactive sources: $^{241}$Am, $^{57}$Co, $^{137}$Cs, $^{152}$Eu, $^{54}$Mn and $^{22}$Na.

4. Data processing
The recorded data for all used radioactive sources are treated as following: the Pedestal-1 is subtracted from the Signal and from Pedestal-2 event-by-event to suppress an effect of slow fluctuation of the base-line; the results of the first step are used to build the pedestal and the signal spectra; the full-absorption peaks are fitted by a Gaussian function that takes into account a non-zero contribution from background events under processed peak and the peak positions are extracted.

The resulting source energy vs peak position dependence (Figure 6) has obviously non-linear behavior due to SiPM intrinsic properties caused by the limited total number of SiPM pixels. That non-linearity is compensated for by defining a calibration function shown in Figure 7 and applying it to all raw data, again on the event-by-event basis, all data now being expressed in energy units. Then all spectra are rebuilt and peak positions ($X_c$) and peak widths (FWHM) are extracted. The final corrected peak position vs source energy plot as well as relative fit residual shown in Figure 8. Figure 9 shows example of spectrum for $^{22}$Na before and after correction.
5. Conclusions
The prototype chip works as was designed. All structural blocks of the chip function properly. Assembly of the SiPMs coupled to the NaI(Tl) scintillation crystal shows very good energy resolution. Measured energy resolution for $^{137}$Cs source is 7.7% (FWHM) while, according to the provided manufacturer certificate, energy resolution for the same NaI(Tl) scintillation crystal coupled with vacuum PMT is 7.5%.

Observed non-linearity in our tests is caused not by chip, but by SiPM itself and can be easily corrected by applying a calibration function.

Test results will be used to correct and refine requirements for the next fabrication run of the chip.

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