Novel SiPM readout method for inter-crystal scatter event identification in PET detectors

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Objective: This study aims to develop a novel silicon photomultiplier (SiPM) readout method that alleviates the readout burden of a positron emission tomography (PET) scanner assembled with one-to-one coupled SiPM-based detector modules, while offering inter-crystal scatter (ICS) event identification capability and maintaining good energy and timing performances.

Methods: For concept verification, we assembled a PET detector that consists of a Hamamatsu 16-channel SiPM array (S14161-3050HS-04) and 4×4 LSO array with a 3.2-mm crystal pitch. The proposed SiPM readout serializes the 16 SiPM anodes into four pulse train outputs encoded with four increasing time-delays in steps of 250-ns intervals. A Sum signal of the 16 SiPM anodes provides the timing information for time-of-flight measurement and a trigger signal for coincidence detection. A time-over-threshold (TOT) method was applied for obtaining the energy information followed by a subsequent TOT-to-energy calibration. The TOT-to-energy calibration curve was generated by fitting the TOT photopeak values of ^{99m}Tc (140 keV), ^{22}Na (511 keV), and ^{137}Cs (662 keV) with a logarithmic function.

Results: We successfully identified the ICS events and determined their interacted positions and deposited energies by analyzing the four pulse train outputs alone, achieving almost a 4-fold DAQ channel reduction of PET detectors than an individual SiPM readout scheme. The occurrence rate of ICS events was 10.85% for the 4×4 PET detector module with 3.2 mm-pitch LSO crystals. The proposed method also yielded good PET detector performances suitable for time-of-flight (TOF) PET application, yielding an energy resolution of 10.9 ± 0.6% and CRT of 285 ± 12 ps FWHM, respectively. In aspect of system development, the proposed method can fully digitalize the timing and position signals, thereby allowing for utilizing a field-programmable gate array (FPGA)-only DAQ system based on precise time-to-digital converters (TDCs).

Conclusion: In this work, we introduced and demonstrated a novel SiPM readout method for ICS event identification in PET detectors, as a replacement of applying individual readout method of PET system. The next milestone is to develop a proof-of-concept PET system that consists of multiple 4×4 block detector modules to demonstrate the scalability of the proposed SiPM readout method.