Development of a scintillator-based photon counting detector for X-ray imaging applications

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The Scintillator-based Photon Counting Detector (PCD) is an advanced detection device that combines scintillator materials with photon counting technology, which can achieve precise detection and counting of individual photons[1]. In X-ray imaging applications such as DR (Digital Radiography) and CT (Computed Tomography), traditional energy-integrating detectors (EID) cannot provide photon energy information, while CdTe/CZT-based direct conversion PCDs, although performing well, face challenges such as high cost, scarce materials, and complex manufacturing. Ultra-fast scintillator materials with nanosecond-scale decay times, high light yield, and excellent energy response characteristics (such as $LaBr_3$:Ce and LYSO:Ce), along with the maturity of silicon photomultiplier (SiPM) technology, also make scintillator-based PCDs more feasible[2]. However, the exponential decay of scintillators can easily lead to signal pile-up, resulting in photon count loss and distortion of the energy spectrum. This paper proposes a deconvolution method based on digital signal processing to improve the counting rate, which performs integration while counting, further extending the dynamic range of imaging.

A scintillator-based PCD has been developed for X-ray imaging applications, which is shown in Figure 1. The scintillator-based PCD consists of the scintillator detector, the SiPM, the ASIC board and the Data Acquisition System (DAQ). SHPIX-SIPM, the self-developed high-count-rate readout ASIC, integrates four channels and each channel consists of a single-end to differential amplifier, a successive-approximation register analog-to-digital converter (SAR ADC), a photon counting module and an energy integration module. The dynamic range of the output count rate of SHPIX-SIPM is improved because of the digital signal processing technology and the integrated energy spectrum.

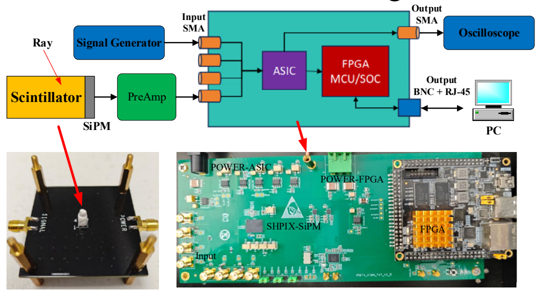

Figure 1 The scintillator-based PCD.

The photon counting module include a digital trapezoidal filter and a multi-channel analyzer. The digital trapezoidal filter can convert a bi-exponential signal into a trapezoidal signal with much shortened pulse width, which is shown Figure 2(a). Pile-up signals can be further identified and decomposed, which can improve the output count rate of the photon counting module, except for those arrives at the rise time of the trapezoidal. The details of the distinction of pile-up signals are shown in Figure 2 (b), (c) and (d). When the photon counting module becomes saturated, the energy integration module can further extend the dynamic range of the output count rate. Figure 3 shows the normalized spectrum and the output count rates (OTRs) with X-ray machine at different current with a 50 MHz sampling rate.

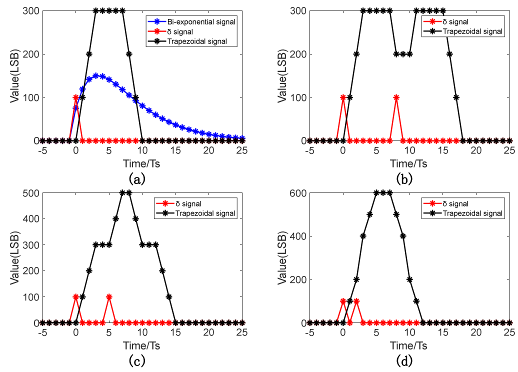

Figure 2 (a) Digital trapezoidal filter shortens bi-exponential signal. (b)(c)(d) Distinction of Pile-up Signals.

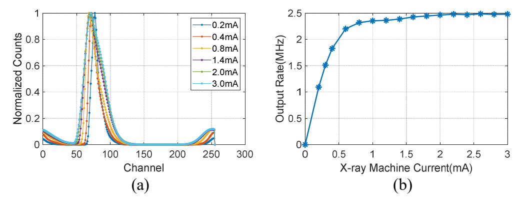

Figure 3 (a) The normalized spectrum with X-ray machine. (b) The OTRs of pile-up distinction module.

[1] L. Bläckberg, "Scintillator-based Photon Counting Detector: Is it feasible?," in 2016 IEEE NSS/MIC/RTSD, 29 Oct.-6 Nov. 2016 2016, pp. 1-5.

[2] S. H. Scott, "The potential of scintillator-based photon counting detectors: evaluation using Monte Carlo simulations," in Proc.SPIE, 2025, vol. 13405, p. 1340537.