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Photon Counting with Arrays of Fully Digital SiPMs –Performance Data, Applications and Comparison to Analogue SiPM's

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In recent years, Silicon Photomultipliers (SiPMs) attracted lot of interest as a replacement for photomultiplier tubes (PMT's) due to their ruggedness, compactness or insensitivity to magnetic fields. Other advantages of solid state detectors are their low operating voltage, low power consumption and large scale fabrication possibilities. However, conventional analog SiPMs still do not exploit the intrinsic digital nature of the underlying Geiger-mode cells due to parasitic capacitances and inductances of the interconnect, the influence of electronic noise and sensitivity to temperature drifts. In addition, they need dedicated readout electronics. The Digital Silicon Photomultiplier (dSiPM, developed by Philips Digital Photon Counting) overcomes those problems by early digitization of the Geiger cell output and integrated electronics (trigger network, time-to-digital converter (TDC), pixel controller) on chip [1].
This digital design provides several advantages for the application of SiPM sensors: The pixel and the pixel controller are highly configurable. Individual Geiger cells can be switched on or off, depending on their dark count performance and validation and integration times as well as readout schemes can be set according to the application needs. In addition, the digital nature and independence from analogue effects such as gain or amplification reduces the temperature sensitivity of the device. Since only digital signals (photon count and time) are provided, subsequent processing electronics are greatly simplified.

For many applications, it is necessary to cover larger areas (cm2 to m2) with detectors. For this reason, individual detector elements are mounted into arrays. We developed arrays of dSiPMs (see Fig.1) which consist of 4 x 4 chips (dies), each containing 2 x 2 dSiPMs (pixels), resulting in a 8 x 8 dSiPM (pixel) matrix. The outer dimension of the array is 32 mm x 32 mm, thus covering about 11 cm^2. Compared to earlier versions of the sensor (presented in [2]), a higher level of integration was achieved by developing a new version of the array that uses an FPGA on the backside. A flash memory, also located on the array, stores all relevant information to operate the array, like configuration settings and look-up-table entries for TDC and photon count corrections. A temperature sensor is included for easy temperature tracking. Due to the high integration, a 32-pin connector is sufficient to interface to the detector array. Figure 2 shows the block diagram of the array.

To demonstrate the performance of the detector array, we investigated its intrinsic performance with respect to timing resolution, PDE, linearity and other factors. In addition, the performance of the arrays in reading out scintillators used for e.g. PET and TOF-PET applications will be presented. Coincidence measurements between two arrays using a Na22 source are conducted and energy and timing resolution per pixel are analyzed. The results are compared to those from similar sensors built with analogue SiPM's (aSiPM's).

References:

[1] Th. Frach et al., "The Digital Silicon Photomultiplier –Principle of Operation and Intrinsic Detector Performance", NSS-MIC Conference Record, 2009

[2] C. Degenhardt et al., "Arrays of Digital Silicon Photomultipliers –Intrinsic Performance and Application to Scintillator Readout", NSS-MIC Conference Record, 2010

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