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A Compact, High Density γ-Detection Module for Time-of-Flight Measurements in PET Applications

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We present a very compact γ-detection module primarily designed for PET applications. On a total area of ≈ 30×30 mm2, 144 SiPM photo detectors coupled to scintillator crystals are read out individually with fast timing ASICs. The core of the module is a LTCC ceramic substrate with internal water channels for efficient and stable liquid cooling. The top side of the LTCC is covered by 12 × 12 SiPMs in a regular pitch of 2.5 mm. The SiPMs are designed in the RGB-HD technology from FBK with a single cell size of 25 × 25μm2, very low dark-count rate and stable performance over a wide temperature range from 0 to 20° C. The readout of the SiPMs is done with 4 specialized PETA5 ASICs flip-chip mounted to the bottom side of the substrate. Each chip has 36 readout channels (available in single or differential ended configuration) with self triggered hit detection, a very low noise discriminator, signal amplitude integration and digitization, a TDC with 50ps binwidth, neighbor logic and fast veto mechanisms. The full height of the assembly, including the connector to the main readout board, is less than 1 cm. In a 1:1 coupling configuration with 10 mm high LYSO scintillator arrays for detection of 511 keV gammas, the module has already reached 200 ps CRT time resolution (FWHM in coincidence between channels on two different modules), sufficient for ToF operation in PET. We present the module design, details on chip operation and latest results with LYSO arrays.

Collaboration

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Summary

The combination of Time-of-Flight capability and good spatial resolution is a mandatory requirement for gamma detectors in
PET systems to improve the lesion detectability in clinical applications. Strict constraints on the detector size are also to be
considered for an eventual integration of the PET system inside a MR scanner.
Addressing these challenges, we have designed a very compact 144-channels gamma detector module with ToF capability and an integrated cooling system.
The detector is based on a single Low Temperature Co-fired Ceramic substrate with an area of ≈ 30 × 30mm2. The top side of the module is populated with 6 × 2 Silicon Photomultiplier (SiPM) dies, each containing 2 × 6 channels. Overall 12 × 12 photo detector elements are arranged in a regular pitch of 2.5 mm across the whole area. The
wire bond pads of the individual SiPM dies are located at one short edge to move all bond wires outside of the crystal area.
The connections between the individual SiPMs and the pads are shaped such that the resistivity is kept roughly constant for
all elements.
The fast readout of 144 channels is performed by 4 PETA5 ASICs (Position Energy Timing Asic) flip chip

mounted on the
bottom side of the same substrate with a bumping pitch of 272 µm. PETA5 is the last generation of the PETA chip family: it
is designed in 180 nm CMOS technology for fast-timing readout and offers self-triggered hit detection. The input impedance
is as low as 7 Ohm. PETA5 includes a programmable neighbor logic (required in light sharing readout mode to trigger neighbors
of a channel with a high amplitude signal), a fast veto mechanism (to abort processing of noise hits or hits with insufficient
amplitude), a very low noise discriminator and tunable threshold per channel. The SiPM gain can also be adjusted on a per-channel basis by changing the dc input level by ≈ 0.8 V . A TDC with 50 ps bin width provides fine time stamp of the events. Two PLL circuits locked to a reference clock of 622.5 M Hz are fully integrated in the chip so that almost no space consuming external components are required on the substrates, except for few decoupling capacitors and LVDS termination resistors.
The module is cooled using an internal liquid channel inside the ceramic substrate, which allows to reach a homogeneous and
stable temperature in < 30 s.
LYSO scintillator arrays with crystals of 2.25 × 2.25 × 10mm3 have been glued in a 1:1 coupling configuration to the SiPMs.
Two identical modules are operated in a dedicated coincidence test setup at 150 mm distance. Using a 22Na point source, a
state-of-the-art time resolution for such crystals of ≈ 200ps (FWHM in coincidence) has been obtained at 22°C in first tests.

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