Development of a PET module using Silicon Photomultipliers as Photon Detectors

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Positron Emission Tomography (PET) is a non-invasive method for in-depth and in-vivo imaging of tissue. The positron emitted in a β^+-decay of the nucleus slows down in the tissue and subsequently annihilates with a nearby electron. The annihilation gamma-rays of 511 keV are usually detected indirectly, through scintillation in inorganic crystals. Photon detectors, like Photomultiplier Tubes (PMTs), detect the scintillation light. The majority of PET devices use PMTs, but due to their size, relatively poor ratio of active to total surface and high price, which is a significant fraction of the total cost of the device, it is worthwhile to search for alternative detectors for visible and infrared photons. The sensitivity of PMTs to magnetic fields and the increasing requirement to unify different image modalities in one measurement, provides an additional reason to search for new detectors. For instance one would like to incorporate a PET apparatus inside a MRI magnet for simultaneous imaging of tissue function and density.

Aside combining different techniques science & engineering continuosly aims to increase the perfomance of tools and techniques. One of the next steps would be to further enhance the signal-to-noise ratio of a PET camera. By using Time-of-Flight (TOF) information from the positron-electron annihilation event, one would be able to increase the performance by a more accurate localisation of the annihilation event, thus increasing S/N. Obviously to enable the use of TOF (light travels ∼33 ps/cm) one requires a sufficiently fast detector, electronics and scintillation crystal. Essentially in the past technologies and scintillation materials were not advanced enough to make TOF PET a feasable technique to increase S/N, even though in the 1980's the obtained timing resolution was on the order of 500 ps [1]. Important factors that had a great impact on the overall performance of the PET camera include the low light yield, bad energy resolution of scintillation materials, instability of the fast electronics and the very expensive photomultipliers required.

During the last decades there has been a tremendous progress in available technologies (detectors & fast electroncs) and scintillation materials that have renewed the interest in TOF PET. This progress is partly due to the rapid advancements in the semiconductor industry where Very Large Scale Integration (VLSI) processes enable the production of cost effectice detectors and electronics, yet still maintaining the proper characteristics for use in a TOF PET camera. Digital waveform samplers like BLAB [2–4] based samplers or the Domino Ring Sampler [5] (DRS) are ideal candidates to be used for the electronics. A new type of semiconductor detector, the Silicon Photomultiplier (SiPM) looks very promising [6–8] to be used as a photon detector.

A Silicon Photomultiplier is a pixelated Geiger mode Avalanche Photodiode (G-APD) with a high gain (∼10^6). The pixelated structure of a SiPM gives it a wide linear dynamic range and an adequate energy resolution to be used as photo sensor for PET applications. It is inherently insensitive to magnetic fields and has a good timing resolution (∼100-200 ps) for very low light intensities (single photo electron level). However it is important to note that the pixelated structure does not provide any spatial sensitivity and only contributes to the dynamic range of the device. Spatial sensitivity is obtained by coupling a segmented scintilator array to an array of SiPMs. Thanks to the low cost and the low power consumption (V_{op} ∼20-100 V) per device, building such an array of SiPMs does not present many issues. Combine these low cost & power benefits with the low power consumption and low cost per channel that waveform samplers like BLAB and DRS offer, it presents itself as a natural combination.

This project aims to exploit the characteristics of SiPMs, novel scintillation materials and waveform samplers to develop a PET module with good spatial, time and energy resolution. The project is divided into 3 main work packages and one extra optional work package that depends on time constraints and opportunities (i.e. availability of a magnet system,...). Below follows a short summary of the main work packages with their points of action. The main focus of the project lies on the combination of the scintillation crystals with the SiPMs while still allowing room for the exploration of the use of a waveform sampler as the readout electronics.

Work Package 1: Study characteristics individual components

- Compare and test characteristics of single SiPMs from different companies
- Test different scintilator materials and crystal samples from different companies
- How can waveform sampling be used to enhance timing resolution?

Work Package 2: Design & building of the module

- Simulate combination of crystal geometry and SiPM array
- Choose optimal SiPMs / Scintillation crystals to build a prototype module
- Design electronic circuit for the module

Work Package 3: Testing the module

- Testing of a single prototype module
- Test 2 prototype modules in a PET setup
- Use the modules to reconstruct an image
- Study the influence of using time of flight information on image reconstruction

Work Package 4: Optional extra tests

- Impact of waveform sampling on the time of flight operation
- Test the modules in a magnetic field (depends on availability of a test magnet)

References

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