Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 571 (2007) 312–316
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

A front-end readout mixed chip for high-efficiency small animal PET imaging

N. Ollivier-Henry*, J.D. Berst, C. Colledani, Ch. Hu-Guo, N.A. Mbow, D. Staub, J.L Guyonnet, Y. Hu

Institut Pluridisciplinaire Hubert-Curien, UMR 7178 CNRS/ULP, 23, rue du Loess, 67037 Strasbourg Cedex, France

Available online 9 November 2006

Abstract

Today, the main challenge of Positron Emission Tomography (PET) systems dedicated to small animal imaging is to obtain high detection efficiency and a highly accurate localization of radioisotopes. If we focus only on the PET characteristics such as the spatial resolution, its accuracy depends on the design of detector and on the electronics readout system as well. In this paper, we present a new design of such readout system with full custom submicrometer CMOS implementation. The front end chip consists of two main blocks from which the energy information and the time stamp with subnanosecond resolution can be obtained.

In our A Multi-Modality Imaging System for Small Animal (AMISSA) PET system design, a matrix of LYSO crystals has to be read at each end by a 64 channels multianode photomultiplier tube. A specific readout electronic has been developed at the Hubert Curien Multidisciplinary Institute (IPHC, France). The architecture of this readout for the energy information detection is composed of a low-noise preamplifier, a CR-RC shaper and an analogue memory. In order to obtain the required dynamic range from 15 to 650 photoelectrons with good linearity, a current mode approach has been chosen for the preamplifier. To detect the signal with a temporal resolution of 1 ns, a comparator with a very low threshold (~0.3 photoelectron) has been implemented. It gives the time reference of arrival signal coming from the detector. In order to obtain the time coincidence with a temporal resolution of 1 ns, a Time-to-Digital Converter (TDC) based on a Delay-Locked-Loop (DLL) has been designed. The chip is fabricated with AMS 0.35 μm process. The ASIC architecture and some simulation results will be presented in the paper.

PACS: 85.40.−e; 29.40.Mc; 29.40.Gx

Keywords: Positron Emission Tomography; Gamma radiation; Detector; Spatial resolution; Temporal Resolution; Electronic readout; Charge measurement; Trigger

1. Introduction

The Positron Emission Tomography (PET) system is based on a noninvasive imaging technique which allows clinical diagnosis by measurement of the metabolic activity.

The PET principle is explained in Fig. 1. A radioactive tracer is injected in blood circulation. The areas with high concentration of radioactive tracer are detected with a scanner after data processing.

The PET physical principle is based on detection of annihilation γ radiation. The annihilation of a positron emitting by the radiotracer and an electron of the matter leads to the creation of two photons. These photons have energy of 511 keV and are emitted in opposite directions. The quantity of γ radiation is proportional to the local concentration of radioactive isotopes.

2. A multi-modality imaging system for small animal (AMISSA)

The AMISSA system incorporates three modalities dedicated to small animal: Computed Tomography (CT),

*Corresponding author.
E-mail address: Nicolas.Ollivier-Henry@IReS.in2p3.fr (N. Ollivier-Henry).

0168-9002/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2006.10.090

Single Photon Emission Computed Tomography (SPECT) and PET. In this paper, we only emphasize on PET.

The requirements on PET systems such as spatial resolution, temporal resolution and high detection efficiency are important for biological research.

The spatial resolution of PET imaging depends on several limiting factors such as detector size, annihilation photon noncollinearity and positron range.

We want to achieve a spatial resolution of 1 mm^3, a temporal resolution of 1 ns and a detection efficiency of about 10%. With these parameters, the images reconstructed after the processing will be enough precise for small animal PET requirement.

The PET dedicated to small animal uses the same types of crystals as the human PET, but they have a reduced size. Here, we use new type of crystal: Lutetium Yttrium Oxyorthosilicate (LYSO) combined with photomultipliers. Fig. 2 shows the arrangement of LYSO crystals coupled with photomultipliers.

In our AMISSA PET design, a matrix of LYSO crystals has to be read at each end by a 64 channels multi-anode photomultiplier tube. The size of the LYSO crystal is of $20 \times 1.5 \times 1.5\,mm^3$. The crystals are placed longitudinally according to the body axis of the animal. This arrangement allows achieving high precision and good detection efficiency.

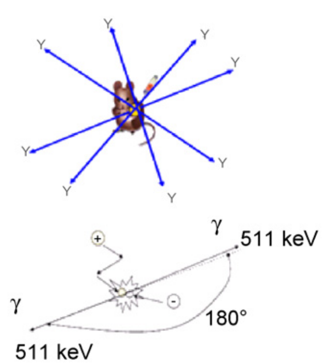

Fig. 1. Physical principle of PET.

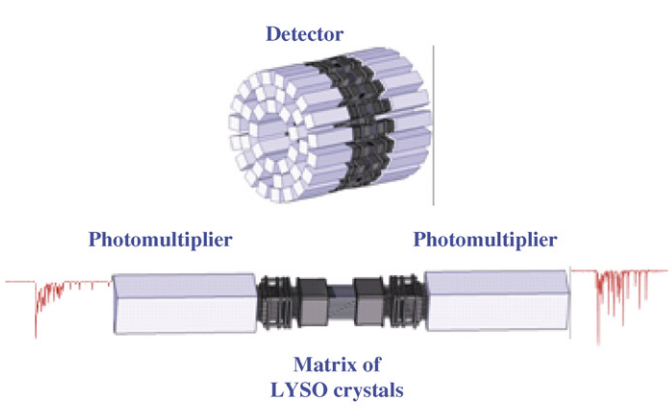

Fig. 2. Arrangement of LYSO crystals coupled with multi-anode photomultipliers.

For 1 mCi source placed at the centre of the system, the frequency of the hits in one crystal is of 100 kHz and the frequency of the single photoelectron is on the order of 1 kHz. The dynamic range was obtained by Monte Carlo simulations and is from 15 to 650 photoelectrons [1].

3. Electronic readout

3.1. ASIC final architecture

The ASIC final architecture with 64 channels is presented in Fig. 3 as a functional block diagram. Each channel consists of an amplification stage with switchable gain of either 1 or 8. The gain of 8 corresponds to the calibration mode where the dynamic range is from 0.3 to 3 photoelectrons. However, in the normal mode the dynamic range is from 15 to 650 photoelectrons and the gain is set to 1. After the preamplifier, there is a discriminator and a future TDC based on DLL. In order to have a serial output, to control easily the bias and also for the testability of the chip, some blocs such as multiplexer, JTAG interface, bias DAC, Low Voltage Differential Signalling (LVDS) driver and serializer have been added in the ASIC. The JTAG protocol is used to set up the DACs, and to test the chip. The serializer allows reading in series the signals from the TDC. The LVDS pads allow reading out the TDC serial data with a clock frequency of 100 MHz.

The topology of one channel is shown in Fig. 4. Each channel is subdivided into two parts:

- an analogue part which performs the signal energy measurement, and
- a digital part allowing obtaining the temporal data corresponding to the arrival time of the first detected photon.

In order to minimize the crosstalk between the channels, a low-input impedance preamplifier has been used. The photomultiplier is directly coupled to its input. The global gain of the preamplifier must however be adjusted online precisely because the gain of the 64 channels of photomultipliers are not uniformed. In the analogue part, the signal at the output of the preamplifier is integrated by an RC network and is then shaped through a slow shaper before being stored in an analogue memory. The digital part consists of a comparator with low threshold (1/3 photoelectron), a monostable and a TDC which is not implemented yet.

3.2. The actual prototype: main blocks of the electronic readout

In this prototype, only 10 channels with charge measurement and discriminator are realised.