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Investigation of Solid State Photomultipliers for Simultaneous PET/MRI Scanner

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1. Introduction

Positron emission tomography (PET) scanners which enable quantitatively to measure physiological indication by in-vivo imaging of biochemical substances in body have been used for investigation of biochemical and pathological phenomena, diagnosis of disease, judgment of prognosis after treatment. Magnetic resonance imaging (MRI) scanners provide anatomical information and are not harmful to subjects unlike CT. A combined PET/MRI imaging system simultaneously providing anatomical details and physiological information would be a great advance in imaging technology [1], [2].

The major obstacle of a combined PET/MRI system has been photomultiplier tubes (PMT) for detector modules in PET scanners because PMTs are extremely sensitive even to the very low magnetic field. Because of this limitation, solid state photomultipliers (SSPM) have been developed to replace standard PMTs [3]. The SSPMs are especially strong in magnetic field because of their intrinsic characteristics.

We present in this report test methods and results of SSPMs coupled with LYSO crystals under normal and 3-T MRI environments.

2. Methods

2.1 SSPM-LYSO coupling and Data Acquisition System

The SSPMs (SSPM-0604BE-CER) were obtained from Photonique SA in Switzerland [4]. To estimate essential characteristics of the SSPM-LYSO coupling, we measured an energy resolution of the SSPM-LYSO coupling exposed to a ^{22}Na positron source. A lucite structure was used to fix the SSPM-LYSO coupling and the ^{22}Na positron source. A SSPM signal was amplified through a preamplifier obtained from Photonique SA in and processed with a VME/NIM system. Non-magnetic electronic elements were used for detection circuits shielded with copper plates of 0.15 mm thickness to protect the electronic elements from the radio-frequency (RF) field of 3-T MRI. CAEN V965 VME ADC and V775N VME TDC modules were used for signal processing. Since the VME/NIM system and power supplies to the SSPM and electronics were placed outside a MRI room, ~20 m long cables were used to extract the SSPM signals to the VME/NIM system.

2.2 Performance in 3-T MRI environments

The SSPM-LYSO coupling with ^{22}Na was placed inside a head coil while the shielded-electronics module was placed outside the head coil but inside the magnet. A cylindrical phantom of a 7.5 cm diameter and 10.0 cm length filled with water was used to evaluate the MRI performance with and without the SSPM-LYSO couplings and the shielded electronics modules inside the human 3-T MRI. We measured an energy resolution of the SSPM-LYSO coupling under five different experimental setups: outside magnet, under the 3-T static magnetic field inside MRI, simultaneous data acquisitions during gradient echo, spin echo and T2 weighted sequence. The simultaneous data acquisition lasted 2 min for each gradient echo, spin echo and T2 weighed sequence. Because of the short duration of the data acquisition, coincidence measurement to study time resolution was not attempted. Figure 1 shows the apparatus being inserted into the 3-T human MRI.

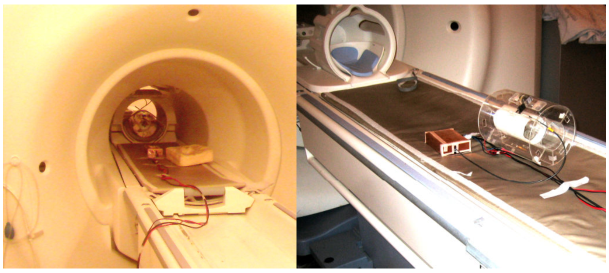

Figure 1. Experimental apparatus placed into the 3-T MRI.

3. Results

3.1 Characteristics of SSPM-LYSO coupling for non-magnetic condition

Because of the mini-cell structure of the SSPM, a raw pulse from SSPM is given by the sum of individual pulses resulted from individual mini-cells exposed to photons. Figure 2(a) shows a raw pulse captured with the Tektronix oscilloscope. As shown in Figure 2(a), the raw pulse consists of overlapping multiple short pulses.

Figure 2(b) shows the ADC distributions obtained with the Photonique amplifies which operated in 5V. The applied voltage to the SSPMs was 58V. Energy resolution of SSPM module was 24.8%.

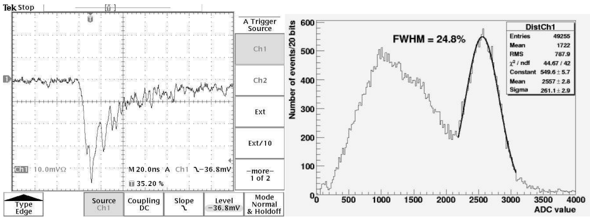

Figure 2. Raw pulse from the SSPM-LYSO coupling (a), and ADC distribution (b) for non-magnetic condition.

3.2 Performance in 3-T MRI environments

Figure 3(a) and 3(b) respectively shows ADC distributions obtained under the 3-T magnetic field and during the gradient echo sequence. Table 1 shows summary of test results of the SSPM-LYSO coupling under the five different experimental setups. The 'Outside magnet' setup indicates the SSPM-LYSO and the electronics inside the MRI room but outside the MRI scanner. The energy resolution (25.9%) of 'Outside magnet' is similar to the energy resolution of non-magnetic condition (24.8%). But energy resolution became worse under the 3-T magnetic field inside the MRI and three different MRI pulse sequences. The shifts in photoelectric peak positions were primarily caused by the 3-T magnetic field while spin echo and gradient echo sequences added extra noises to the SSPM signal. These factors make energy resolution worse. Nonetheless, energy resolutions in the MRI scanner are not too bad for PET scanners.

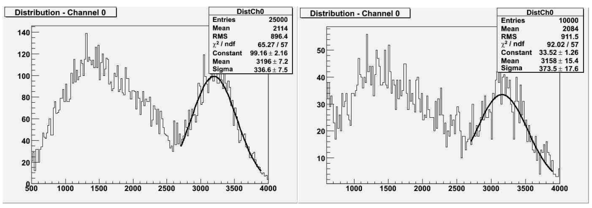

Figure 3. ADC distribution under the 3-T magnetic field (a), during the gradient echo MRI sequence (b).

Mode	Photoelectric peak	Resolution FWHM (%)
Outside Magnet	2833	25.9
Inside Magnet	3196	27.3
Spin echo	3158	30.7
Gradient echo	3149	31.9
T2 weighted sequence	3173	30.9

Table 1. Photoelectric peak and energy resolution in each setup.

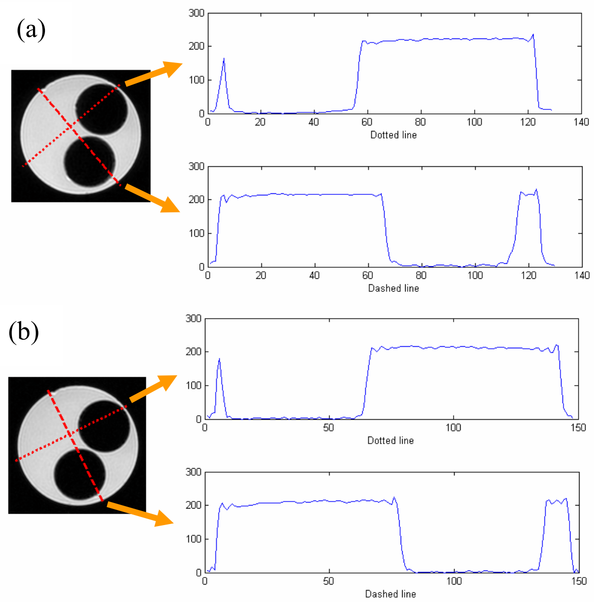

Figure 4. MRI Phantom image without (a) and with (b) the SSPM-LYSO coupling and the electronics in T2 weighted sequence.

Figure 4(a) shows a phantom image without the SSPM-LYSO coupling and the electronics inside MRI. Figure 4(b) shows a phantom image obtained from the simultaneous data acquisition during the T2 weighted sequence with the SSPM-LYSO coupling and the electronics. There is no remarkable difference between without and with the electronics. Therefore, the SSPM-LYSO coupling and the electronics do not affect the MRI images.

3. Conclusion

We have investigated SSPMs with an emphasis to be used in simultaneous PET/MRI scanners. We obtained a 25% FWHM energy resolution in non-magnetic environment and a ~30% FWHM energy resolution during various MRI pulse sequences. The SSPMs showed steady performance during various MRI sequence inside the 3-T magnetic field and did not affect the MRI images. Consequently we conclude that solid state devices would have a good potential to be used for the simultaneous PET/MRI scanners.

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