DESIGN AND TESTING OF A NEW SCINTILLATION PROBE FOR THE PAL SPECTROMETRY — PART I*

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A new version of measuring probe for PAL spectrometry was designed and tested. Unlike commercial scintillation heads, silicon photomultipliers (SiPMs) were used as scintillation light detectors. The tests were carried out with two types of SiPMs (KETEK and ONSemi) and various scintillation materials, such as LYSO, BaF_2 and BC412.

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1. Introduction

The standard scintillation probe used in positron annihilation lifetime spectroscopy (PALS) consists of an electron photomultiplier tube (PMT) and BaF_2 scintillator [1, 2]. The BaF_2 is characterized by the very fast scintillation emission with a time of 800 ps at 220 nm [3]. However, the use of an electron photomultiplier significantly reduces the convenience of system outside the laboratory and in conditions of high magnetic fields (*e.g.* in connection with NMR). A new approach to more handy detection devices consists in application of SiPMs.

The main features of SiPMs are: amplification comparable to photomultiplier tube (PMT), small dimensions (down to 1×1 mm^2), low bias voltage (~ 26 V) and the ability to work in magnetic fields [4]. The aim of our tests is to show which combination of elements will be the best for the PALS applications and allow to create a new mobile PALS spectrometer (mPALS). Main advantages of such an mPALS are: reduced size, increased safety in hazardous environment (no high voltage), and insensitivity to magnetic field fluctuations (which is the main weakness of PMT's).

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The advantages as above will allow to create a new spectrometer to use for cancer diagnostics in hospital facilities.

2. Experiment

Three scintillators were selected for testing: LYSO, BaF_2 and BC412 all with dimensions $6 \times 6 \times 30$ mm^3. LYSO is characterized by intense and relatively fast scintillation (~ 45 ns). BaF_2 is one of the fastest crystalline scintillators, commonly used in PALS. BC412 is a plastic scintillator, the fastest of all used here, however, no photopeak in the amplitude spectrum is present, and triggering the start and stop pulses using the "Compton edges" is necessary. Three semiconductor photomultipliers: ONSemi F-Series 6×6 mm^2, ONSemi C-Series 6×6 mm^2 and KETEK PM5325 $4,7 \times 4,7$ mm^2 were tested.

Each of the scintillators was connected with SiPM via optical contact. The detection set consists of three modules: photomultiplier power supply with low-pass filters, fast and slow signal extraction path (Fig. 1). The fast path was connected to the "FAST" pin of the SiPM output. The operational amplifier (THS3201) works in inverting mode. No filter systems are used. A slow module was connected to the photomultiplier anode. The preamplifier amplifies the signal by 29 dB, then active filtering forms a bipolar pulse with a duration of about 2 μs. Parallel to the slow output, a single-channel analyzer system has been installed to be used as a gate.

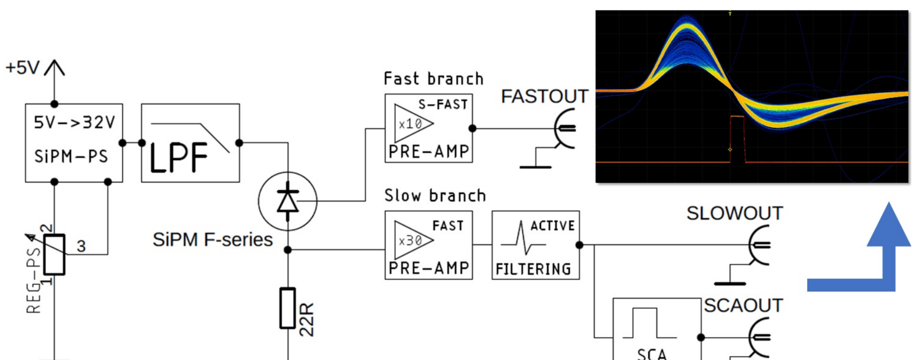

Fig. 1. Block diagram of the mPALS measuring probe. Slow pulse and gate are shown on oscillogram.

3. Results and discussion

1. SiPM's analysis for the fast-amplified output.

The tests take into account the pulse rise and decay time, as well as the pulse amplitude while maintaining maximum photon detection efficiency. Assessment of the above parameters allows to verify the usefulness of the new probes for the PALS technique. Table I shows the results for the BC412 scintillator combined with three types of SiPM's. The use of a plastic scintillator is economically advantageous (low price compared to other scintillators). The tests have shown that with BC412, one obtains the best performance when using the F-series SiPM.

TABLE I

Risetime (RT), falltime (FT) and 511 keV amplitude for BC412 and 3 types of SiPMs.

SiPM	RT [ns]	FT [ns]	Pulse height of γ 511 keV Compton edge	Suitable for PALS
F-Series	3.1	160	2.8 V	Yes
C-Series	9.0	211	2.2 V	No
PM5325	32	970	1.7 V	No

2. Scintillators test for the fast-amplified output.

Basing on the results of the semiconductor photomultiplier parameters further tests of suitable scintillators were performed with ONSemi F-Series 6×6 mm^2 system. Three scintillators: LYSO, BaF_2 and BC412 were tested (Table II). The pulses for each scintillator are shown in Fig. 2.

TABLE II

Risetime (RT), falltime (FT) and 511 keV amplitude for BC412 and 3 types of scintillators.

Scintillator	RT [ns]	FT [ns]	Pulse height of γ 511 keV Compton edge	Suitable for PALS
BC412	3.1	160	2.8 V	Yes
LYSO	18	230	4.4 V	No
BaF_2	37	210	1.3 V	No fast component

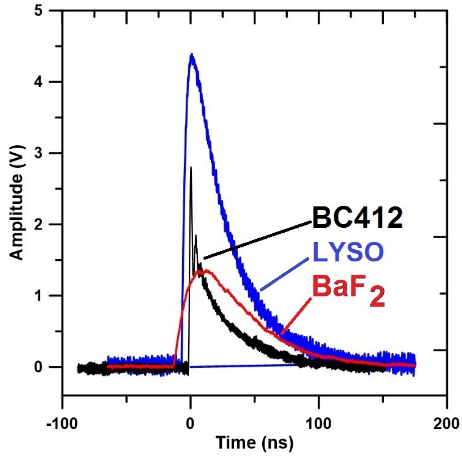

Fig. 2. Pulse shape as seen on the oscilloscope for BC412, LYSO and BaF_2 scintillators connected to ONSemi F-Series.

4. Summary

SiPMs are widely used in high-energy physics [5] and automotive technology [6]. The use of combination SIPM F-Series and BC412 plastic scintillator is the most promising. Other scintillators case increases the pulse rise time, which affects the time resolution. Due to the low wavelength of the BaF_2 component and the low SiPMs Photon Detection Efficiency (PDE), it is not possible to use this type of scintillator like in commercial solutions.

The next step will be to improve the system with more ultra-low noise electronics and enclosing it in a dedicated housing. Two probes will be tested in the PALS spectrometric circuit.

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