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Pulse shape discrimination based on fast signals from silicon photomultipliers

Junhao Yu, Zhiyong Wei *, Meihua Fang, Zixia Zhang, Can Cheng, Yi Wang, Huiwen Su, Youquan Ran, Qingwei Zhu, He Zhang, Kai Duan, Ming Chen, Meng Liu

Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

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ABSTRACT

Recent developments in organic plastic scintillators capable of pulse shape discrimination (PSD) enable a breakthrough in discrimination between neutrons and gammas. Plastic scintillator detectors coupled with silicon photomultipliers (SiPMs) offer many advantages, such as lower power consumption, smaller volume, and especially insensitivity to magnetic fields, compared with conventional photomultiplier tubes (PMTs). A SensL SiPM has two outputs: a standard output and a fast output. It is known that the charge injected into the fast output electrode is typically approximately 2% of the total charge generated during the avalanche, whereas the charge injected into the standard output electrode is nearly 98% of the total. Fast signals from SiPMs exhibit better performance in terms of timing and time-correlated measurements compared with standard signals. The pulse duration of a standard signal is on the order of hundreds of nanoseconds, whereas the pulse duration of the main monopole waveform of a fast signal is a few tens of nanoseconds. Fast signals are traditionally thought to be suitable for photon counting at very high speeds but unsuitable for PSD due to the partial charge collection. Meanwhile, the standard outputs of SiPMs coupled with discriminating scintillators have yielded nice PSD performances, but there have been no reports on PSD using fast signals. Our analysis shows that fast signals can also provide discrimination if the rate of charge injection into the fast output electrode is fixed for each event, even though only a portion of the charge is collected. In this work, we achieved successful PSD using fast signals; meanwhile, using a coincidence timing window of less 3 nanoseconds between the readouts from both ends of the detector reduced the influence of the high SiPM dark current. We experimentally achieved good timing performance and PSD capability simultaneously.

1. Introduction

The pulse shape discrimination (PSD) technique is an effective means of particle identification. It is based on differences in the pulse shapes of scintillation signals induced by the interactions of fast neutrons and gamma rays in organic scintillators [1]. The fluorescence process in a plastic scintillator is commonly described as consisting of two decay components. The interactions of different particles in the scintillator result in different ratios between the fast and slow components. For example, the scintillation signals from neutron events exhibit a much more prominent slow component than the scintillation signals from gamma-ray events. Consequently, a difference arises in the attenuation characteristics of these signal waveforms. This phenomenon is the basis for the PSD technique [2].

PSD has been widely used in liquid organic scintillators, but it has only been applied in a few solid scintillators. Indeed, plastic scintillators have traditionally presented poor PSD properties [3]. However, a breakthrough has been achieved in solid organic plastic scintillators that makes the use of PSD in solid plastic scintillator detectors possible.

Conventional photomultiplier tubes (PMTs) are generally considered to be an effective means of reading out the optical signals from scintillators. However, PMTs have many disadvantages, such as their large volume, their high power consumption, their high voltage needs and, especially, their sensitivity to magnetism. Now, a new type of silicon photomultiplier (SiPM) has begun to see widespread use by virtue of its small volume, low power consumption, low voltage and insensitivity

* Corresponding author.
E-mail address: wzy_msc@nuaa.edu.cn (Z. Wei).

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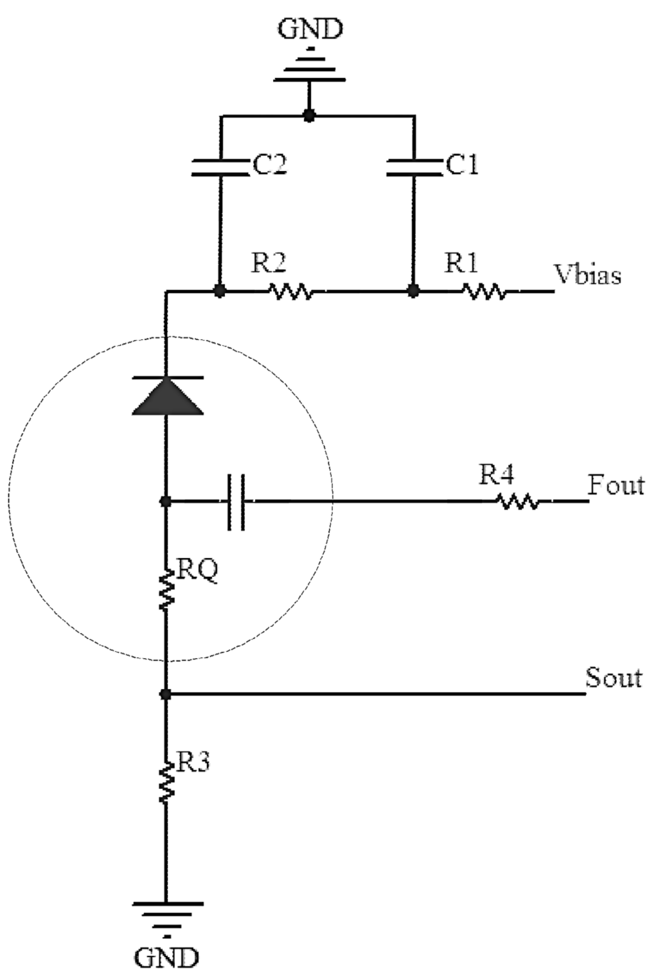

Fig. 1. The circuit schematic of the photoelectric conversion unit.

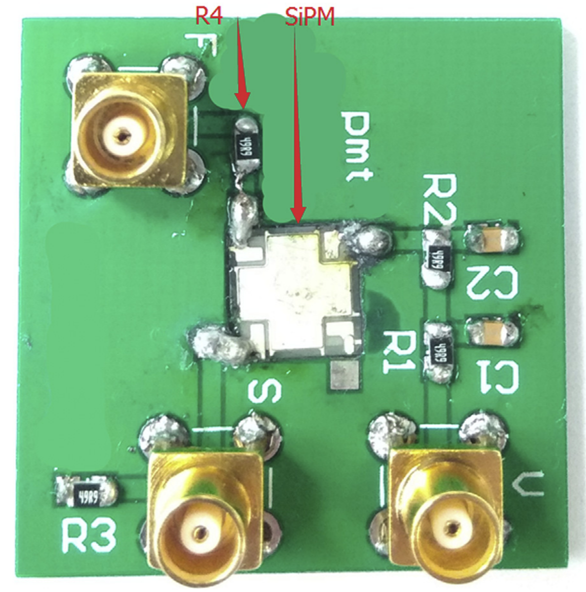

Fig. 2. A photograph of the circuit in the photoelectric conversion unit.

to magnetic fields [3]. Consequently, such SiPMs are applied in many diverse applications.

Fast signals have shorter time durations and thus offer more accurate timing performance compared with standard signals, and they can be applied for counting and timing purposes just like differential signals. For example, differential signals are traditionally used for counting in nuclear electronics. In our work, the waveforms of the fast signals are similar to those of differential signals. It has been proven that a detector consisting of a plastic scintillator coupled to a SiPM can discriminate between fast neutrons and gamma rays [4]. We use an EJ-299-33A scintillator and a SensL SiPM FC in our work. The SensL SiPM FC has two outputs: a fast output and a standard output. Many studies have been conducted based on standard signals, but to date, fast signals have been ignored. However, in addition to the other potential advantages, the ability to use fast signals for PSD would eliminate the need for two sets of systems for counting and signal acquisition, which increases the burden of electronics and data processing. Therefore, in this study, we present our findings on PSD using fast signals.

2. Experiment

The most significant component of the experimental setup used in this study is the photoelectric conversion unit. The key device in the photoelectric conversion unit is the SiPM. The method of electronic connection to the fast output is different from that for the ordinary standard output. As shown in Fig. 1, when we wish to obtain a standard signal, a positive bias voltage is applied to the cathode, and the current signal is read out from the anode (the standard output). The conversion of the current signal into a voltage signal is accomplished by the signal amplification unit. However, this method of electronic connection is not suitable for fast signals because of the lack of a discharge circuit. Fast signals are coupled through a built-in capacitance, and the lack of a discharge circuit causes the signal charge to accumulate at both ends of the capacitor, which can lead to the formation of a reverse voltage that builds up until the signal can no longer be transmitted in a short time. Therefore, a ground resistance (R3) is necessary to form a discharge circuit and to achieve the conversion from a current signal to a voltage signal in the photoelectric conversion unit. The resistance value should not be too large, or it can lead to instability. In our experimental setup, we use a 50 Ω resistance. We also use a 50 Ω resistance at R4 for impedance matching.

The dimensions of the scintillator are 6 mm × 6 mm × 130 mm, and it is coupled to a MicroFC-60035-SMT SiPM. The dimensions of the photoelectric conversion unit are 30 mm × 30 mm, and the SiPM is in the center, as shown in Fig. 2.

The fast signals are amplified in the preamplifier unit and digitized in a DT5751 digitizer. The preamplifier unit is a simple amplifier circuit designed by us; it is depicted in Fig. 4. The data stream is continuously written to a circular memory buffer in the digitizer. When a trigger occurs, the FPGA writes the next N samples following the trigger and freezes the buffer so that it can be read via USB or an optical link. Then, acquisition can continue without dead time in a new buffer. Finally, the data are recorded by the data processing unit. In this study, we used an elongated solid plastic scintillator and read out signals from both ends. During data processing, we used time-correlated measurements [5] to exclude false events. The overall system connections are shown in Fig. 5. The plastic scintillator, the photoelectric conversion unit,