A Detector Capacitance Compensation Technique for SiPMs

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1. Introduction

The silicon photomultiplier (SiPM) is now widely used as a replacement of a traditional photomultiplier tube (PMT) in radiation related applications because of the better quantum efficiency around 80% compared to ~ 40% of high-end PMT products as well as lower power consumption and smaller occupying area. Additionally, the manufacturing cost is more competitive in mass production.

Recently, these promising devices have been rapidly disseminated in high energy physics, nuclear security, and advanced medical imaging instruments, such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT). For these applications, innovative signal multiplexing methods have also been proposed to reduce the number of readout channels [1-3]. However, previous work suffers from performance degradation in signal-to-noise ratio (SNR) and timing due to large capacitance accumulated by shorted SiPMs.

In order to mitigate the effect on large detector capacitance, a bootstrap technique [4] was proposed to cooperate with a conventional charge-sensitive amplifier (CSA), so that the combination retains the signal pulse height and rising time even though detector capacitance increases. This technique exploits the Miller effect, to enable highly multiplexed readout of SiPMs with minimal information loss.

In this work, we describe the configuration of the proposed multiplexing circuit and present experimental results to verify the feasibility of the channel number reduction technique while maintaining pulse amplitudes.

2. Configuration of the Readout Circuit

Typically, through a resistor on the high voltage supply or ground, a SiPM is coupled to a CSA as a preamplifier to amplify voltage signals which are converted by the induced charge formed. The initial output voltage before the preamplifier is simplified to

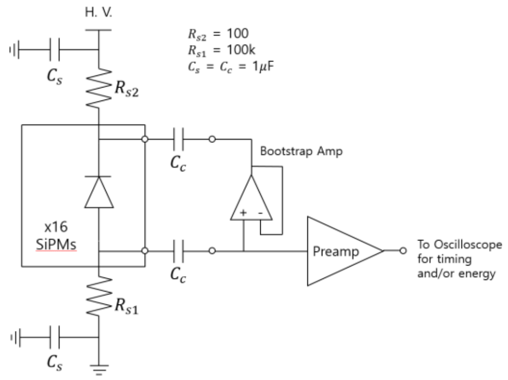

Fig. 1. Configuration of the proposed multiplexing method for an array of 16 SiPMs with bootstrap compensation.

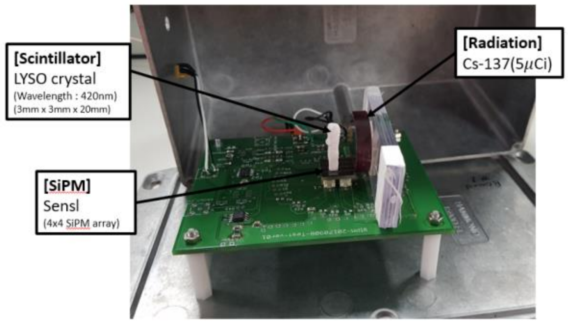

Fig. 2. Completed sensor and circuit in an aluminum box for reducing signal interference.

$V_{ini} = Q/C_D$ where Q is the charge generated from a radiation impact event and C_D is the SiPM capacitance. In conventional channel multiplexing, the initial voltage signal is decreased as the number of shorted SiPMs increases.

Fig. 1 shows the configuration schematic with a 16 SiPM array (Sensl, MicroFJ-30035-TSV) coupled with the bootstrap amplifier, referred to a unity-gain amplifier used to mitigate the increased capacitance when multiplexing, resulting in completed Printed Circuit Board(PCB) design as shown in Fig. 2. One side of the SiPM is connected to the input of the voltage amplifier while the other side is fed by the unity-gain amplifier to transfer the voltage transition across the SiPM, such that the voltage difference across the SiPM becomes ideally zero, resulting in no presented intrinsic capacitance.

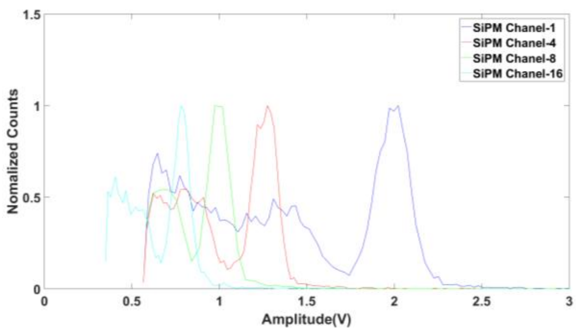

Fig. 3. Non-compensated gamma spectrum of ^{137}Cs.

3. Initial Results and Conclusion

For observing the proposed compensation effect described above, we first measured radiation spectrum of ^{137}Cs based on different multiplexing ratios of 1, 4, 8, and 16, providing detector capacitance increase. Without the bootstrap technique as illustrated in Fig. 3, the output signals show degraded pulse heights in amplitude (each waveform in time domain shows rising time degradation either). After enabling the compensation technique as shown in Fig. 4, the results show notable improvements of the signal amplitude on the x-axis in spectrum.

In conclusion, the novel multiplexing scheme using a unity-gain amplifier for a bootstrap technique successfully enhances signal amplitudes even though SiPM channels are combined. Now we are preparing for time resolution measurement to validate usage for time dominant applications such as PET.

The main advantage of the proposed multiplexing method is that can be adopted in any applications requiring high performance which is correlated with rising time and amplitude of pulses. As a practical example, the next generation PET systems generally contain thousands of SiPMs, resulting in critical overhead on readout electronics complexity, including inter-connections, routing, components, and power consumption. The proposed configuration can greatly reduce the number of preamplifiers while maintaining the pulse shapes without losing information, increasing cost, complexity, and footprint of required readout electronics.

Between now and the conference presentation, we plan to do more experiments for plotting better compensation ability related to energy and timing resolutions as well as perform theoretical analysis on electrical behavior of the components for a more deep understanding of the circuit properties.

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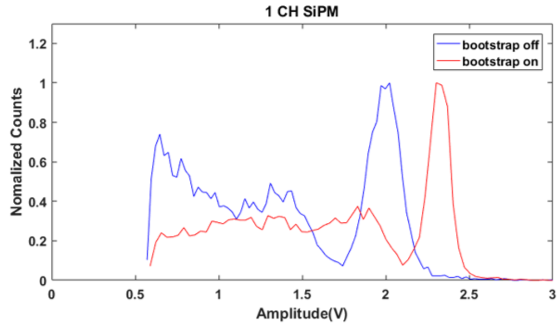
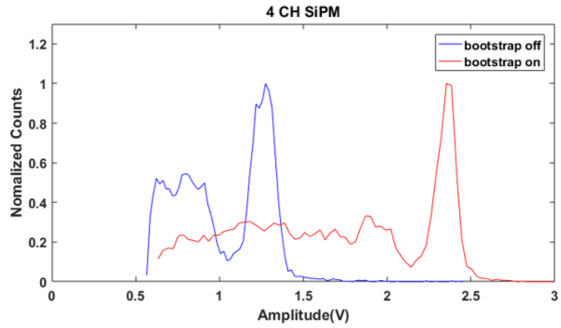
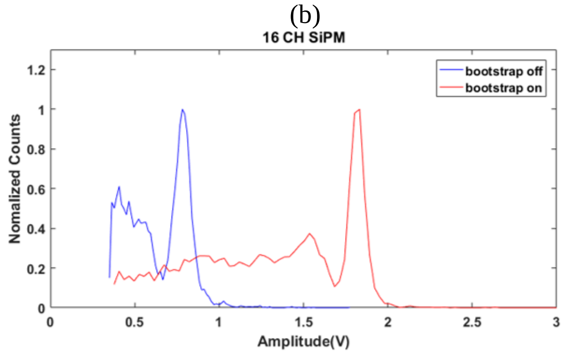


(a)



(b)



(c)

Fig. 4. Successfully compensated gamma spectrum of ^{137}Cs with and without the bootstrap technique.

References

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