A Highly Tunable ASIC Prototype for Reading Out Scintillators and Providing Real-Time Pulse Shape Discrimination

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Introduction

The development of a high-performance, application-specific integrated circuit (ASIC) for reading out scintillators and providing real-time pulse shape discrimination (PSD) is crucial for various applications, including neutron imaging and non-proliferation detection. This paper presents a detailed design and implementation of a highly tunable ASIC prototype that can be used to classify fast neutrons from gamma rays in a portable and compact pixelated neutron camera.

Design Objectives

- Develop an application-specific integrated circuit (ASIC) to serve as a front-end system for read-out of plastic/organic scintillator materials when coupled to SiPMs, while providing real-time pulse shape discrimination (PSD).
- Demonstrate key electronics needed for a portable and compact pixelated neutron camera.
- Ensure maximum programmability/tunability of all parts of the chip design for a first prototype and that all important nodes are available as external outputs.
- Real-time fast neutron/gamma PSD is implemented through an analog version of a ratio partial/total integration of incident waveform.
- The ASIC contains a synthesized digital core that allows for high tunability and programmability of various parts of the parallel integration setup. This allows for use with various plastic/organic scintillator materials.
- The ASIC front-end system is now designed for variable gain and dual-polarity input capability.

Summary of PSD_CHIP_v2 Design

- The second prototype ASIC we have developed, PSD_CHIP_v2 is a 4CH design.
- The chip is designed to read out SensL’s line of SiPM arrays, with each SiPM containing two outputs: a fast capacitively coupled output (FOUT) and a standard resistively coupled output (SOUT). The former is used for triggering and the latter is the input to the real-time PSD circuitry.
- Adjustable gain in the front-end stage can be set from an transimpedance gain of ~30x to ~180x.
- The chip’s front-end consists of a NMOS+PMOS regulated common gate (RCG) amplifier that can either sink or source current depending on polarity of input current pulse from the SiPM cell.

Design of Real-Time Fast Neutron/Gamma PSD

- Each SOUT input signal is split into two fully differential sub-circuits in parallel: one each for total and partial integrations.
- A tunable resistor in the total integration circuit is used to set a threshold on the ratio of partial/total integrals.
- Figure on the right shows results on neutron/gamma separation using this method, albeit implemented in software. A clear range of threshold space is available for optimizing efficiency vs. leakage.
- The PSD threshold can be energy dependent and adjusted to match response of particular scintillators.
- We have implemented fine-tuning of partial (up to 200ns) and total integration lengths (up to 2.5us).
- The tunable resistor value is set by a switchable resistor.

Discussion/Summary

- These prototype chips have 100 I/O pads.
- Input pads include four SiPM pixels’ FOUT, SOUT outputs.
- Output pads include buffered, post front-end FOUT, SOUT waveforms; outputs of partial and total integration channels, subtraction op amp, SOUT classification discriminator output for each of four channels and four digital test buses.
- The synthesized digital core is responsible for all programmability/tunability selection on-chip.
- 62 on-chip 5-bit registers allow for tuning various baseline reference and comparator threshold voltages, the partial and total integration lengths (including fine-tuning per channel), biases for various circuit blocks, etc.
- The chip allows for evaluation of two different designs that implement the programmable digital delay lines necessary for fine tuning of the partial and total integration enable pulses.
- The first method involves a chain of (different length) current starved inverters.
- The inverter gates operate by limiting rise and fall times based on the supplied bias current.
- Bias current is set by a 5-bit current DAC that takes as input the LSB current value.
- This value can be constant or set using an external DAC (it is an input pad to the chip).

Discussion/Summary

- Can theoretically hit any integration window length up to the max value (fixed by the length of the inverter chain).
- Step size/resolution set by external DAC specs and noise limitations.
- The second method involves a voltage ramp generator setup. A T0 pulse starts the linear charging of a capacitor through a (tunable) constant current source, for the total/partial integration enable pulses. When the capacitor voltage hits a selected threshold, the ramp generator resets and brings the enable pulse LOW again.
- The threshold is tunable in 256 linear ~10ns steps for total int and 256 linear ~1ns steps for partial int.

Links to Program Objectives

- The development of a portable neutron camera is part of the NNSA mission for non-proliferation detection applications.
- Its low power consumption makes it suitable for remote deployment.
- The ASIC that is being developed will find use in NNSA related projects outside of the neutron imaging regime.

This material is based upon work supported in part by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number DE-NA0003180.