Design, Fabrication and Characterization of a Bias Supply Circuit for Silicon Photomultipliers

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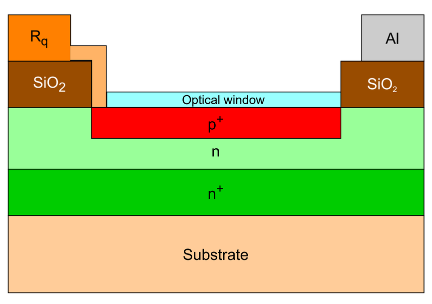
Abstract

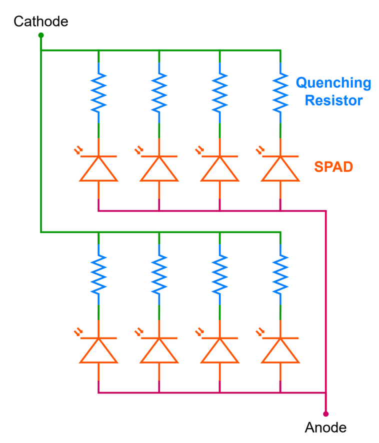
To study the feasibility of a shallow-depth neutrino detector, a Cosmic Muon Veto Detector (CMVD) is being built around the mini-ICAL detector at the IICHEP in Madurai, India. The CMVD will use extruded plastic scintillators for muon detection and wavelength-shifting fibers coupled with silicon photomultipliers (SiPMs) for signal readout. A power supply source is needed for biasing the SIPMs, where the accuracy, precision, and stability of the source are crucial to ensure consistent gain characteristics. We developed a biasing power supply circuit capable of sourcing 50-58V in 50 mV steps and up to 1mA of current. It features digital voltage adjustment and stabilization, as well as current monitoring capabilities using an external controller such as microcontrollers. In addition to providing better flexibility, the controller enables possibilities such as temperature compensation. Designed to power multiple SiPMs, this circuit can be easily integrated with the front-end electronics of SiPMs.

About SiPM

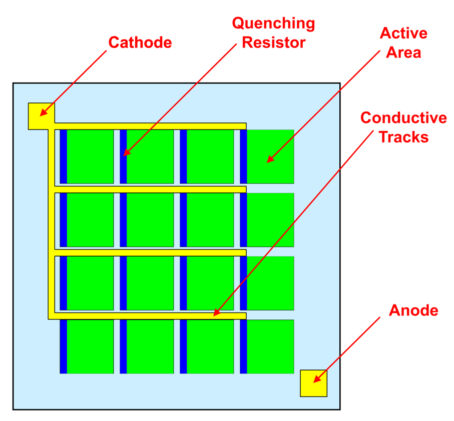
Silicon photomultipliers (SiPM), a.k.a. Multi-Pixel Photon Counters (MPPC) are the solid-state equivalent of traditional PMTs that feature high gain (10^5 to 10^6), small size, higher photon detection efficiency (20%-50%) compared to PMTs, and insensitivity to magnetic fields. However, they have a high dark noise rate (~100 kHz), non-linear characteristics, and lower energy resolution compared to PMTs.



A single SPAD



Multiple SPADs in parallel



Physical construction

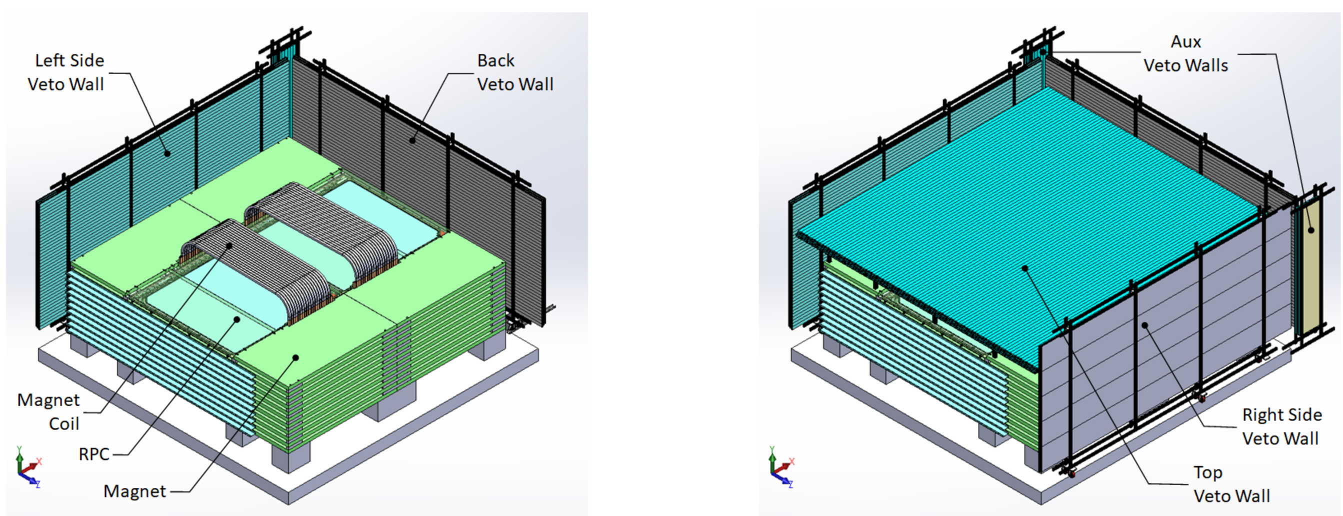
The gain of a SiPM is given by:

$$\mu = \frac{(V_{BIAS} - V_{BD}(T))C_J}{q_e}$$

Hence, the stability of V_{BIAS} is extremely crucial for the gain stability.

Why We Made This Device?

Due to the high flux of cosmic muons, there are huge backgrounds from the cosmic ray muons to the muon coming from neutrino interactions. Hence, a veto detector is required that surrounds the neutrino detector. For the INO experiment, the main neutrino detector is a 50kT iron calorimeter (ICAL) consisting of alternate layers of glass RPCs and iron plates. A 1/600-scale prototype detector named mini-ICAL has been constructed in IICHEP, Madurai, India. A Cosmic Muon Veto Detector (CMVD) has been proposed that will cover the mini-ICAL, and will consist of plastic scintillators and SiPMs. To reliably power more than 3000 SiPMs in the CMVD, a number of well-designed power supply modules are required.



CMVD covering the mini-ICAL at IICHEP, Madurai.

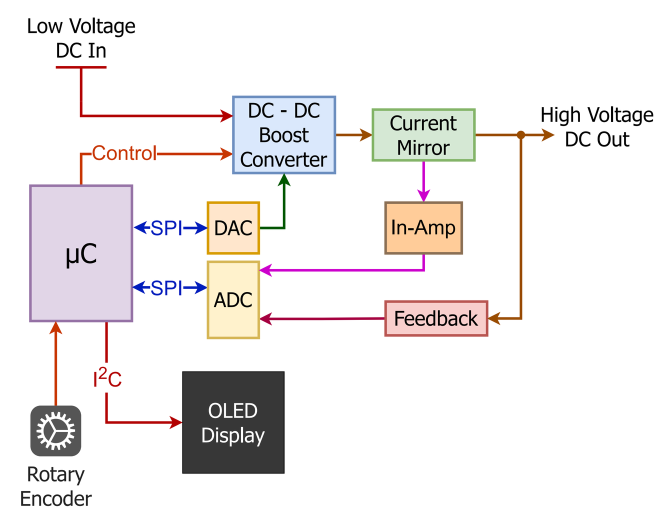
Design Specifications

- Grouping 40 SiPMs with closest breakdown voltage values.
- Bias Voltage range 50 to 56 V.
- Bias voltage smallest control step of 10 mV or less.
- Current capacity of 25 µA (more than 10x the actual requirement).
- Current readout least count 500 nA or better.
- Over-current protection.
- Soft start.
- Voltage control and current readout to be digital.

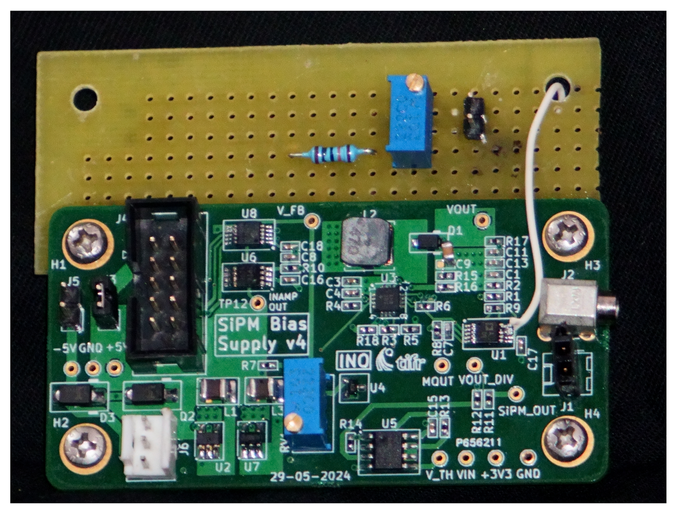
Salient Features

- Microcontroller controlled DC - DC boost converter.
- Digital voltage adjustment and readout.
- P.I.D control loop for stabilization.
- Current readout using current mirror.
- User interaction using a rotary knob and a small display.

Design Insights

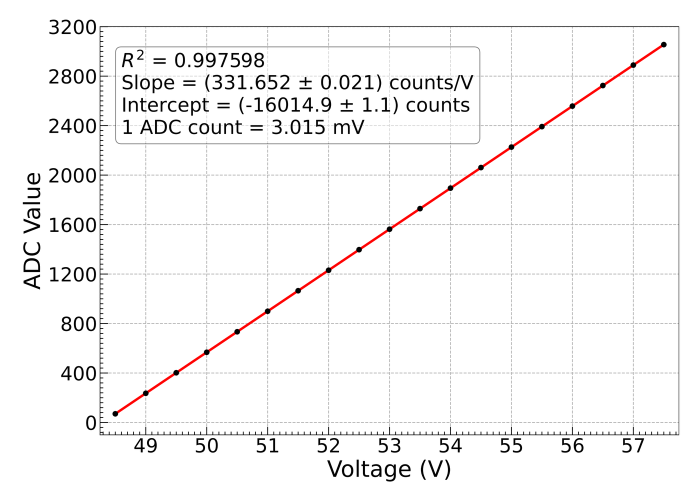


Block diagram

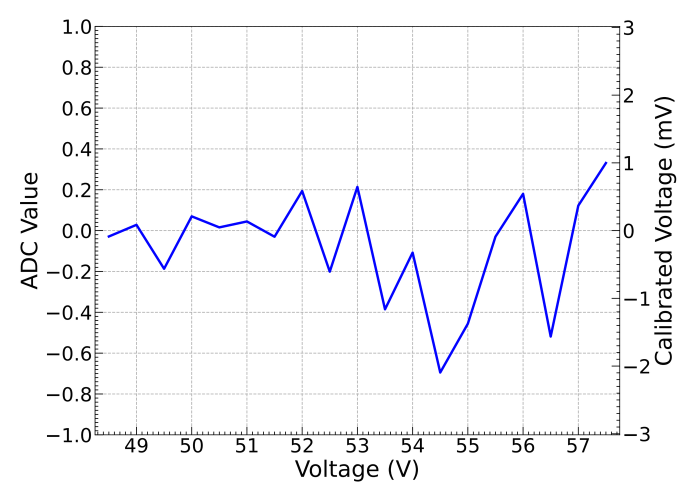


Fully assembled PCB

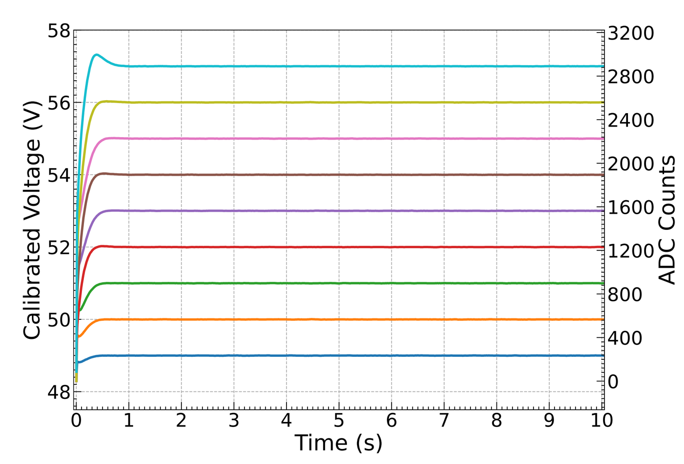
Results



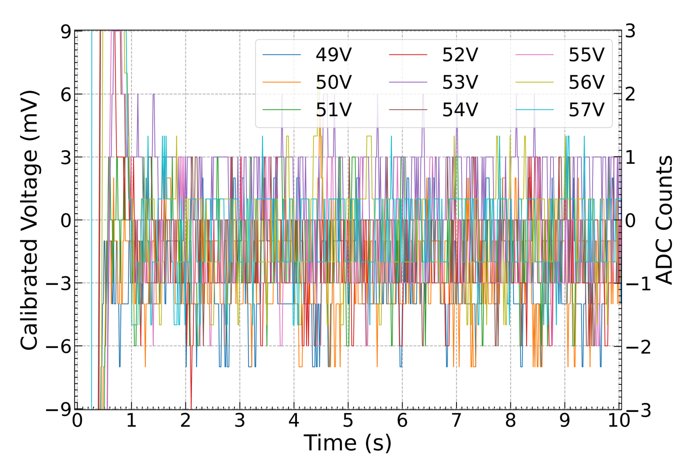
Voltage calibration - linearity



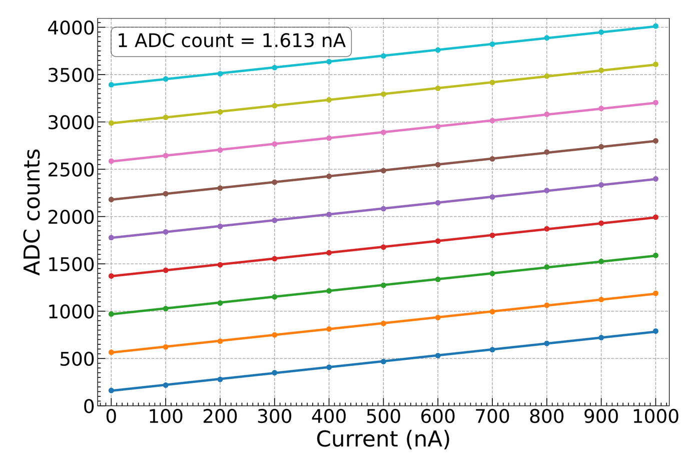
Voltage calibration - DNL



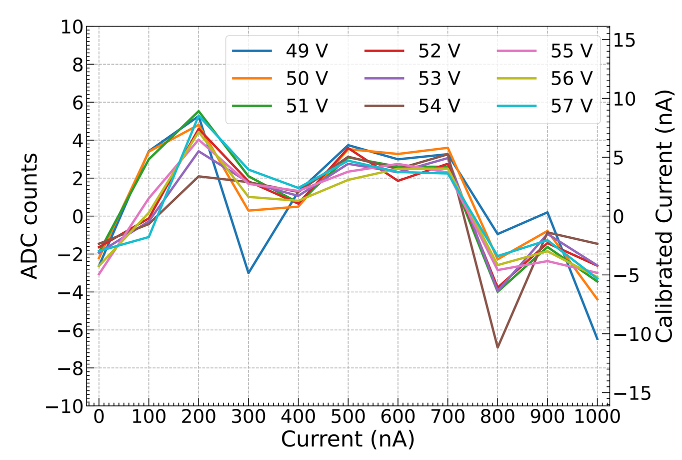
Step response after PID tuning



Step response - differential



Current calibration - linearity



Current calibration - DNL

Future Goals

- Improve current readout precision and noise.
- Develop methods for automatic calibration.
- Test for load and line regulation.
- Test for output voltage stability over temperature.

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