PROCEEDINGS OF SCIENCE

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

Prajjalak Chattopadhyay,* Mandar N. Saraf, Gobinda Majumder, Satyanarayana Bheesette and Ravindra R. Shinde

Tata Institute of Fundamental Research, 1, Dr. Homi Bhabha Road, Mumbai, India
E-mail: prajjalak.chattopadhyay@tifr.res.in, mandar@tifr.res.in, gobinda@tifr.res.in, bsn@tifr.res.in, rrs@tifr.res.in

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.

42nd International Conference on High Energy Physics (ICHEP2024)
18-24 July 2024
Prague, Czech Republic

*Speaker

https://pos.sissa.it/

PoS(ICHEP2024)1138

1. Introduction & Motivation

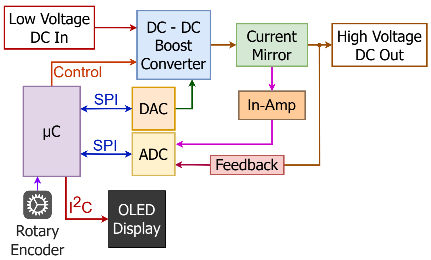
Silicon photomultipliers (SiPMs), a.k.a. Multi-Pixel Photon Counters (MPPCs) are arrays of Single Photon Avalanche Diodes (SPADs), and are the solid-state equivalent of traditional gas-filled PMTs. The gain of a SiPM is given by [1]: $\mu = [V_{BIAS} - V_{BD}(T)]C_J/q_e$, where, V_{BIAS} is the applied reverse bias voltage, V_{BD} is the breakdown voltage at temperature T, C_J is the junction capacitance and q_e is the charge of an electron. Hence, the stability of V_{BIAS} is extremely crucial for the gain stability.

Due to the high flux of cosmic muons, there are huge backgrounds from the cosmic-ray muons compared to the muon coming from neutrino interactions. Hence, for a shallow depth neutrino experiment, a veto detector is required that surrounds the neutrino detector. For the INO experiment [2], a prototype detector named mini-ICAL has been constructed at 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.

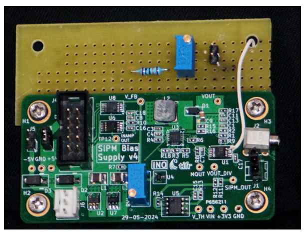
2. Design & Fabrication

The design required the grouping of 40 SiPMs with the closest breakdown voltage values. The planned bias voltage range was 50 to 56 V direct current (DC) with the smallest control step of 10 mV or less. In addition, a current capacity of 25 µA (more than 10x the actual requirement) and current readout least count 500 nA or better was recommended. Other features required were overcurrent protection, soft start, digital voltage control, and digital current readout.

To meet these requirements, a microcontroller-controlled DC-DC boost power supply was designed, which features digital voltage adjustment and readout, along with a proportional-integral-derivative (PID) control loop for stabilization, and load current readout using a current mirror. A simplified block diagram is shown in Fig. 1a. The fully assemebled printed circuit board (PCB) is shown in Fig. 1b.



(a) Simplified block diagram.

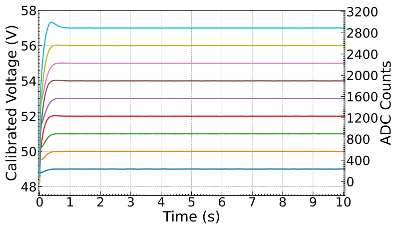


(b) Fully assembled PCB. The microcontroller and user interface elements are not shown here.

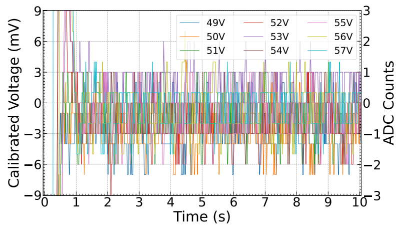
Figure 1: The SiPM bias supply circuit.

3. Results

The first step was to tune the parameters of the PID controller to achieve a stable and robust control loop. To verify, a step function response was observed (Fig. 2). The voltage and current readout calibration was performed after that, and the results are shown in Fig. 3.

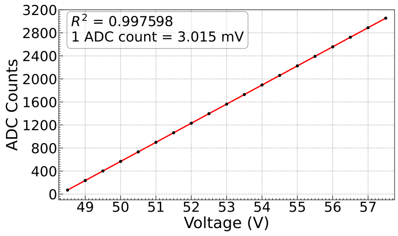


(a) Step response after PID tuning.

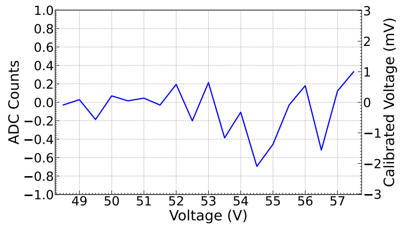


(b) Step response after PID tuning - differential fluctuations.

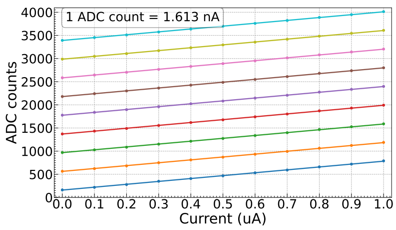
Figure 2: PID loop performance after parameter tuning.



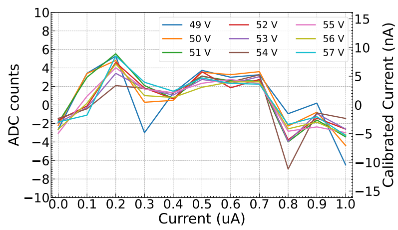
(a) Voltage calibration - linearity.



(b) Voltage calibration - differential nonlinearity.



(c) Current calibration - linearity.



(d) Current calibration - differential nonlinearity.

Figure 3: Voltage and current readout calibration.

4. Conclusion

The output voltages are observed within a few millivolt deviations from the set target voltages, and the non-linearity of the voltage readout is within +1 to −2.5 mV in the operating voltage range of 49 to 57 V. The nonlinearity of the current readout is also mostly within ±10 nA. The device satisfies all our design criteria and is ready to be implemented in the CMVD setup.

References

[1] A.N. Otte, D. Garcia, T. Nguyen and D. Purushotham, *Characterization of three high efficiency and blue sensitive silicon photomultipliers*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **846** (2017) 106.

[2] M. Saraf, P.R. Chinnappan, A. Deodhar, M. Jangra, J. Krishnamoorthi, G. Majumder et al., *Design, fabrication and large scale qualification of cosmic muon veto scintillator detectors*, *Journal of Instrumentation* **18** (2023) P05003.