

# Design and Development of a Plastic Scintillator-based Compact Test and Trigger System with SiPM Readout and Custom Electronics

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## Introduction & Motivation

We intended to produce a self-contained & compact system for testing & characterizing scintillator-SiPM assemblies by measuring their efficiency and to measure differential muon flux using the devices and systems we developed for our primary experiment – the *Cosmic Muon Veto Detector (CMVD)*. [Talk by Mr. Mandar Saraf]

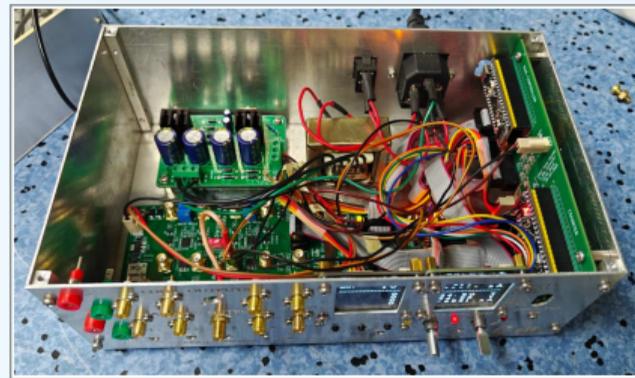
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### This can be used for various purposes:

- Characterization of scintillator-SiPM detectors.
- To set up remote monitoring stations for measurement of differential cosmic muon flux. (*With modification of the arrangement of scintillators.*)
- For education & training purposes.

# Main Features

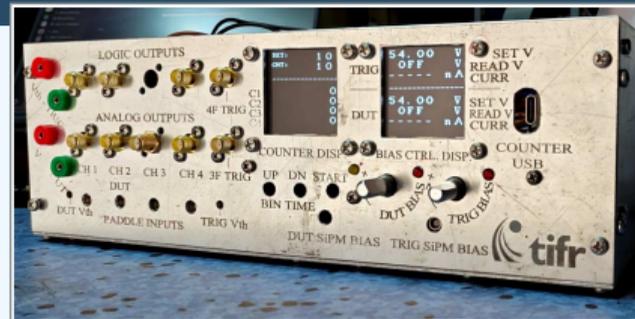
- All hardware and firmware are custom-made.
- Powered directly by  $\sim 230\text{ V}$  power line – built-in low voltage power supply.
- Two independent  $50\text{ V}$  to  $58\text{ V}$  digitally-controlled bias voltage sources for the SiPMs – one for test and one for trigger.
- Self-contained front-end electronics.



## Main Features (Contd.)

- **Microcontroller-based** scaler (counter) for pulse counting.
- **Microcontroller-based** control for SiPM bias voltages.
- **Display** to show the scaler (counter) outputs.
- **Display** to show the SiPM bias voltages and currents.
- **Buttons and rotary switches** to turn on/off & set the SiPM bias voltages, counting windows (time), start counting etc.

**No FPGA!**

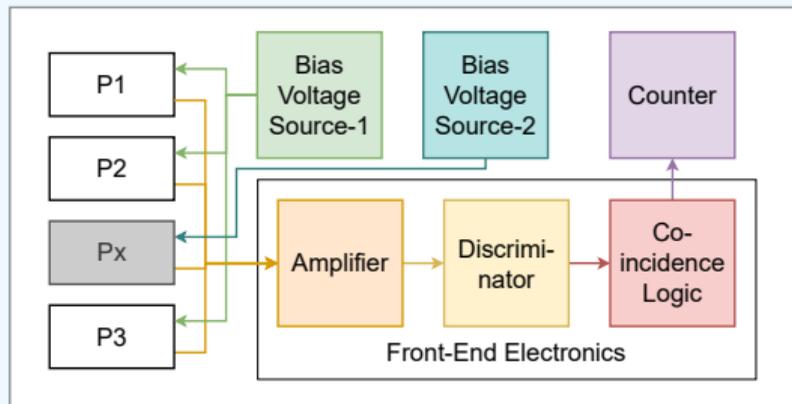


# Overview of the Setup

The design is of a modular approach and hence consists of several individual modules:

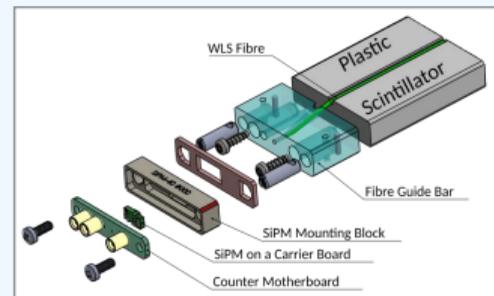
- Low voltage power supply ( $\pm 6\text{ V}$ ).
- SiPM bias supplies (2 units).
- Front-end electronics.
- Scaler (counter) system and SiPM bias control system (combined unit).
- The scintillator and SiPM assemblies.

We will discuss each of these subsystems individually in the following slides.



# The Scintillator & SiPM Assembly

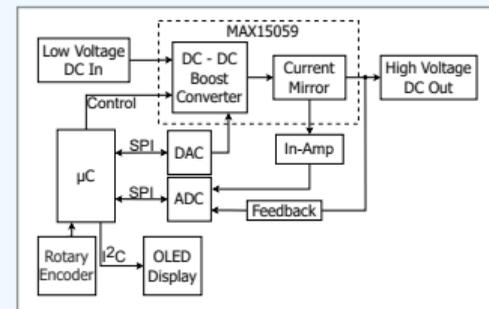
- $(41 \times 10 \times 500)$  mm<sup>3</sup> extruded plastic scintillator paddles with wavelength shifting (WLS) fibers running through a central groove.<sup>a</sup>
- SiPMs at one end on a carrier board.
- Bias voltage in and out connectors for daisy-chaining.
- One signal out connector.



<sup>a</sup>Pla-Dalmau et al (MINOS Scintillator Group). *Frascati Phys. Ser. 21* (2001), pp. 513-522.

# The SiPM Bias Supply

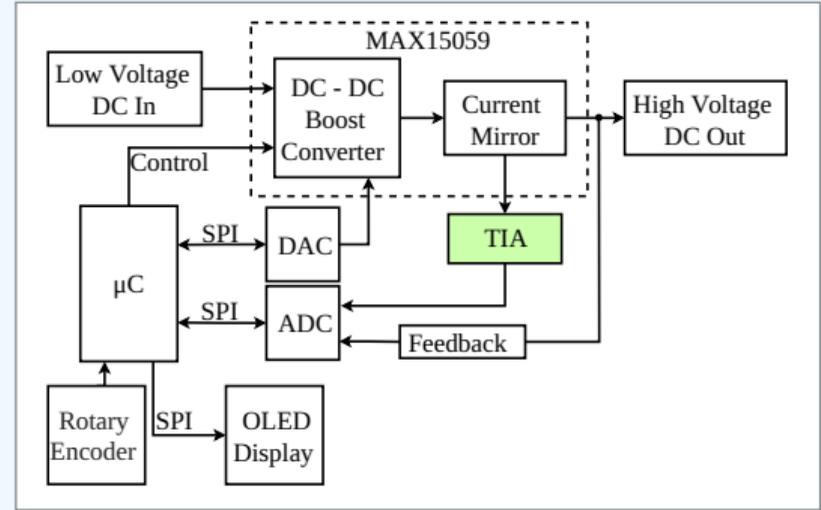
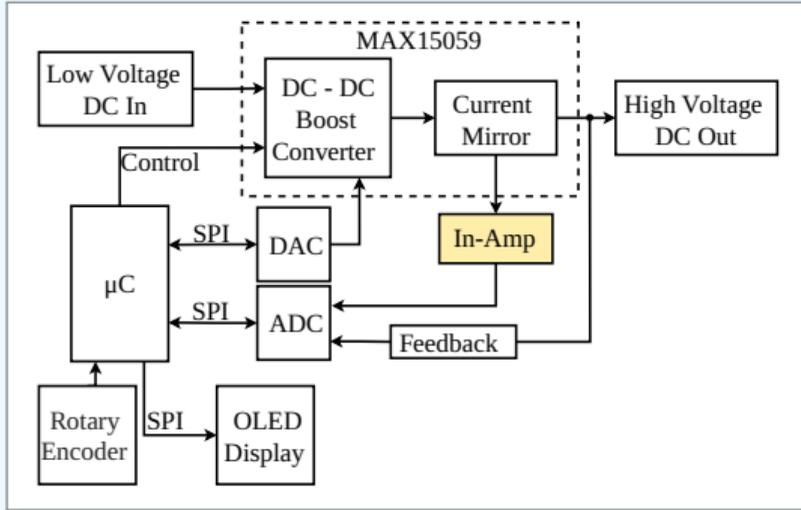
- DC-DC boost topology – 6 V input to 50–58 V.
- Based on MAX15059 IC – designed for APD bias applications: External PID controller for more stability – suitable for SiPMs.
- One STM32 microcontroller running Real-Time Operating System (RTOS) controlling two bias supplies.
- Dual-channel ADC to read output voltage and current.
- Output voltage → input parameter for PID control.
- DAC for voltage adjustment and control: Fed from PID controller output.



Chattopadhyay, P. et al. (2025) "Development, characterization, and testing of a bias supply for SiPMs in the CMVD experiment," *Journal of Instrumentation*, 20(09), p. P09006. DOI: 10.1088/1748-0221/20/09/P09006

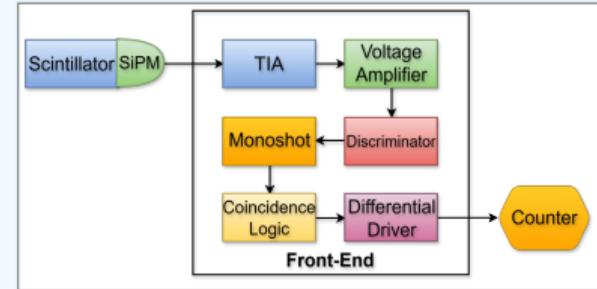
# The SiPM Bias Supply – New Developments

For the current ( $I$ ) readout mechanism, a new **transimpedance amplifier**-based design is being prototyped instead of the existing **instrumentation amplifier**-based design.



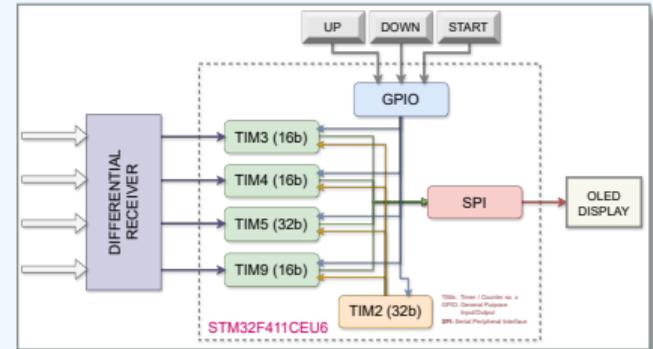
# The Front-End Electronics

- BJT-based high-bandwidth **Transimpedance Amplifier (TIA)**.
- **Op-Amp based voltage amplifier** as the second stage.
- **Discriminator** with threshold adjustment using a **potentiometer**. Independent threshold for **test** and **trigger** channels.
- **Monoshot (monostable multivibrator)** for pulse stretching (pulse width  $\sim 100$  ns).
- **Coincidence logic** (three- and four-fold) using **AND gates**. Output is sent to the **counter** through a **differential driver** – noise immunity.



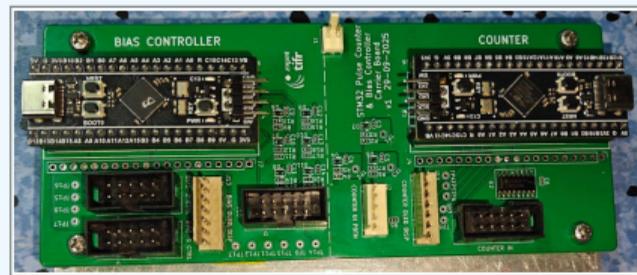
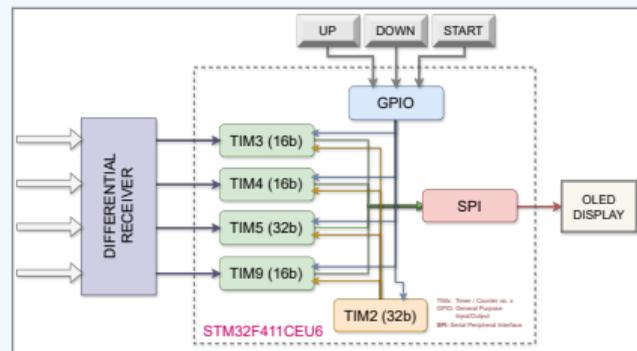
# The Scaler/Counter

- The counter is implemented on another **STM32 microcontroller (MCU)**. This shares a common PCB with the **bias controller**.
- Using a **microcontroller** significantly reduces **cost** and **complexity** compared to **FPGA**-based systems.
- **Differential receiver** converts **LVDS** signals to **TTL** signal → fed to the **MCU**.
- **TIM2 (32b)** timer as timekeeper – **interrupt** driven.



# The Scaler/Counter (contd.)

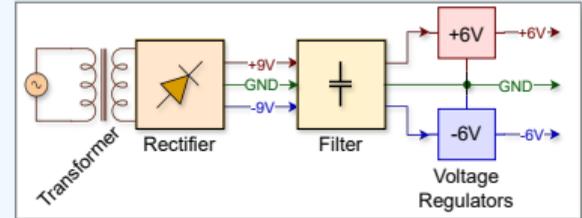
- **TIM3, TIM4, TIM9 (16b) and TIM5(32b)** as counters in **external trigger mode**. 16b counters are converted to **virtual 32b counters** using overflow interrupts. The counter channels are
  - ▶ Test scintillator counts.
  - ▶ One of the three trigger scintillator counts.
  - ▶ Three-fold coincidence.
  - ▶ Four-fold coincidence.
- **Push buttons** and an **OLED display** for user interface.
- **Interrupt-driven** architecture for the time critical sections.



# The Low Voltage Power Supply

For the sake of completeness...

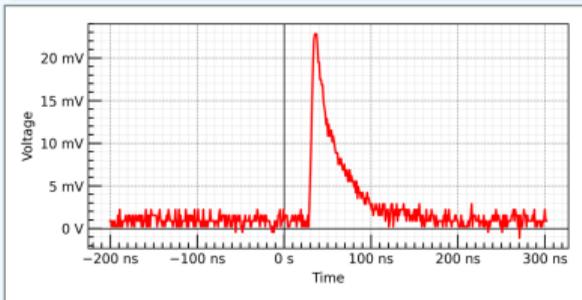
- $\pm 6\text{ V}$  linearly regulated DC power supply.
- Runs directly from  $\sim 230\text{ V AC}$  mains. Galvanically isolated by transformer.
- Capable of delivering  $\sim 300\text{ mA}$  continuous current.
- Fuse protection at the AC input.



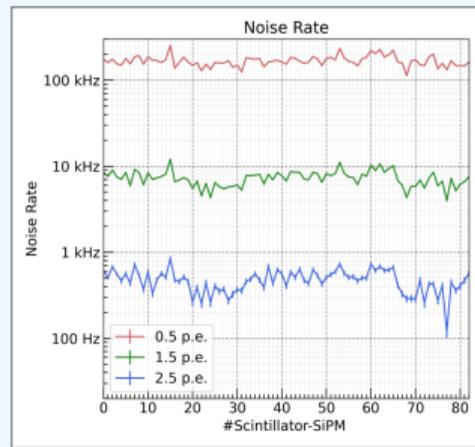
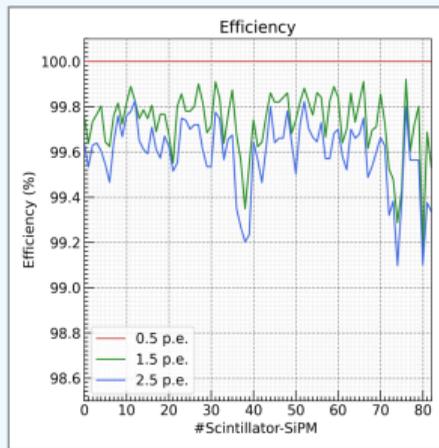
# Scintillator-SiPM Testing Results

So far, almost **150** scintillator-SiPM assemblies have been tested.

*[Poster by Mithilesh Shinde]*



$$1 \text{ pe} \approx 12 \text{ mV}$$



*Efficiency > 99%*

- Testing of the **scintillator-SiPM** assemblies have been completed.
- Presently the **SiPM bias supply circuit** design is being improved. A new current readout mechanism is being designed and tested.
- **Testing and validation** of the **MCU firmware** are underway.
- **Functional testing** of the individual modules are underway.
- **Next step: Integrated testing of the whole system.**
- **Future plan: Add USB support to the counter for PC-based control.**

WORK IN PROGRESS

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**WORK IN PROGRESS**

# List of Publications

## Journal paper:

- Chattopadhyay, P. et al. (2025) "Development, characterization, and testing of a bias supply for SiPMs in the CMVD experiment," Journal of Instrumentation, 20(09), p. P09006. <https://doi.org/10.1088/1748-0221/20/09/P09006>.

## Conference proceedings:

- Chattopadhyay, P. et al. (2025) "Design, Fabrication and Characterization of a Bias Supply Circuit for Silicon Photomultipliers," Proceedings of 42nd International Conference on High Energy Physics — PoS(ICHEP2024). 42nd International Conference on High Energy Physics, SISSA Medialab, p. 1138. <https://doi.org/10.22323/1.476.1138>.
- Chattopadhyay, P. et al. (2025) "Design, Fabrication and Characterization of a Bias Supply Circuit for SiPMs," in L. Singh et al. (eds.) Proceedings of the XXVI DAE-BRNS High Energy Physics (HEP) Symposium 2024, 19-23 December, Varanasi, India. Singapore: Springer Nature, pp. 1361–1364. [https://doi.org/10.1007/978-981-95-1513-4\\_311](https://doi.org/10.1007/978-981-95-1513-4_311).
- Chattopadhyay, P. et al. (2025) "Microcontroller-based Custom DAQ System for Characterisation of Scintillator Paddles," in L. Singh et al. (eds.) Proceedings of the XXVI DAE-BRNS High Energy Physics (HEP) Symposium 2024, 19-23 December, Varanasi, India. Singapore: Springer Nature, pp. 1387–1390. [https://doi.org/10.1007/978-981-95-1513-4\\_317](https://doi.org/10.1007/978-981-95-1513-4_317).
- Chattopadhyay, P. et al. (2025) "Suitability of DRS4 for Readout of SiPMs in the CMVD," in L. Singh et al. (eds.) Proceedings of the XXVI DAE-BRNS High Energy Physics (HEP) Symposium 2024, 19-23 December, Varanasi, India. Singapore: Springer Nature, pp. 1383–1386. [https://doi.org/10.1007/978-981-95-1513-4\\_316](https://doi.org/10.1007/978-981-95-1513-4_316).

Thank You



# Backup

# The SiPM Bias Supply – Firmware

- A single **STM32 microcontroller** running a **Real Time Operating System (RTOS)** to control both the bias supplies.
- **PID control** for the output voltage stabilization.
- **Digital filtering** of the raw **ADC** data.
- **Separate RTOS tasks** for–
  - ▶ **Overcurrent** or **short-circuit** protection.
  - ▶ Two Individual **PID control loops** for test and trigger bias supplies.
  - ▶ Read the **Output current**.
  - ▶ **User input** events handling.
  - ▶ **Display** handling.

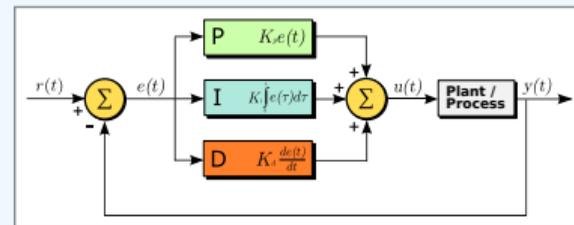


Image credit: Arturo Urquizo / CC BY-SA 3.0

## PID controller logic

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

# Instrumentation Amplifier vs Transimpedance Amplifier

