Journal of Instrumentation

PAPER

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To cite this article: F. Henningsen *et al* 2021 *JINST* **16** C09033

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Published by IOP Publishing for Sissa Medialab

Received: *July 27, 2021*
Accepted: *September 8, 2021*
Published: *September 29, 2021*

Very Large Volume Neutrino Telescope 2021
May 18–21, 2021
Valencia, Spain

A self-monitoring precision calibration light source for the IceCube Upgrade

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Abstract: With neutrino astronomy on the rise, calibration aspects of large-volume detectors are becoming one of the key targets to boost detector performance. In the scope of the IceCube Upgrade planned for the South Pole season of 2022/23, we developed a novel, isotropic, self-monitoring, precision calibration light source. We present the device characteristics as well as first studies of calibration impacts for different detection environments.

Keywords: Detector alignment and calibration methods (lasers, sources, particle-beams); Neutrino detectors; Instrument optimisation

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[1] Full author list and acknowledgments are available at https://icecube.wisc.edu/collaboration/authors/#collab=IceCube-Gen2&date=2021-05-18&formatting=web&tag=VLVnT+2021.

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https://doi.org/10.1088/1748-0221/16/09/C09033

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Contents

1 The precision optical calibration module

Large-volume detectors aim to study light signals induced by neutrino interactions in natural, optical media like water or ice. By means of numerous light sensors within such a medium, the light signal can be reconstructed spatially and temporally in order to study the primary neutrino properties. Naturally, light propagation within the medium as well as detection at the sensors requires proper calibration.

The development of the Precision Optical Calibration Module (POCAM) has been ongoing for several years with first prototypes deployed in the GVD [1] and STRAW detectors [2]. The device itself aims to be a detector-independent, absolutely-calibrated reference light source for large-volume detectors emitting self-monitored, isotropic, nanosecond light pulses of variable intensity, time profile and wavelength. Using such a device provides the possibility to study a variety of optical parameters of the detector medium as well as the sensor units to high precision. The proof of principle has been verified in the two previous prototype deployments.

The recent developments of the POCAM eventually allow an installation within the IceCube Upgrade [3] in order to tackle existing detector systematics [4, 5]. In total 21 POCAMs will be installed throughout the volume of IceCube on seven new strings for the Upgrade. This work outlines the current status of the POCAM developments for the IceCube Upgrade.

1.1 Instrument concept

As described in more detail in [6], the device consists of several parts which are developed in close cooperation with various companies:

- Pressure housing — Encapsulating the instrument internals in order to allow installation in extreme environments.
- Optical components — Diffusing sphere which makes the light pulse isotropic and coated surfaces which allow precise control of the emission profile.
- Analog electronics — Light pulsing and self-monitoring sensor circuitry.
- Digital and interface electronics — Internal device control, DAQ and telescope interface.

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The general layout of the device is shown in figure 1 with the housing comprised of a cylindrical part allowing space for electronics, connectors and vacuum ports as well as the flanges with hemispherical glass domes for light emission. While the device in this state is not actually isotropic, the distance scales in large-volume detectors makes the vertical separation of the two hemispheres insignificant and essentially produces a point source of light within the detection volume.

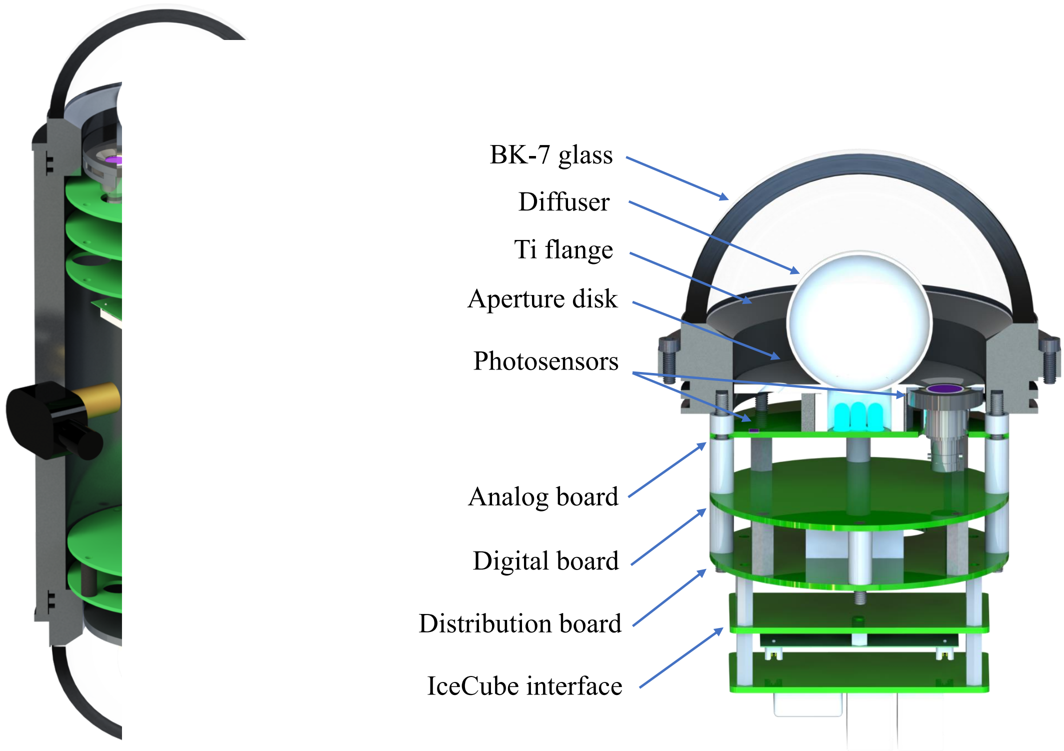

Figure 1. POCAM housing and internal design in full view (left) and in detailed view for one of the flanges (right). For details on the components refer to the text. Figures taken from [6].

1.2 Design

The optical components encompass the diffusing sphere as well as the aperture disk. While the former makes the light pulse isotropic by diffusing and integrating the initial LED pulse, the latter is coated in black to reduce reflectivity and subsequently used for mounting the internal reference sensors. As for analog electronics, the light pulsing circuitry as shown in figure 2 is comprised of a Kapustinsky flasher circuit [7], in both a fast and default configuration, as well as a laser diode driver based on industrial designs [8]. While the former is used solely on light-emitting diodes, the latter can drive laser diodes (LD) and achieves higher intensities at moderate pulse widths. With these three driver circuits we achieve a dynamic range of 10^6–10^{11} photons per pulse at pulse widths of 1.2–25 ns full-width half-maximum (FWHM) and for wavelengths of 365, 405, 450 and 520 nm. Exemplary outputs for these pulsers with respect to intensity and time profile are given in figure 3. For the reference sensors, a Silicon-Photomultiplier (SiPM) as well as a photodiode are used in order to encompass a large dynamic range of potential self-monitoring. Both are read-out using operational amplifier chains and both provide a small- and a high-gain channel in order to increase dynamic range.

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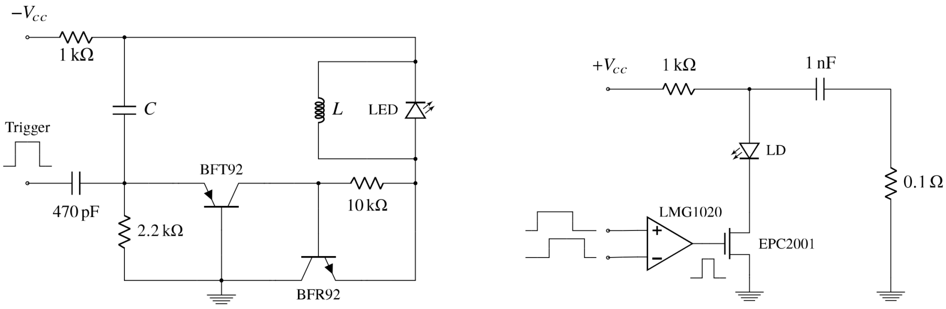

Figure 2. POCAM light pulser circuits. Shown here are the Kapustinsky driver (left) and the LD-type driver (right) for driving LEDs and LDs, respectively. Figures taken from [6].

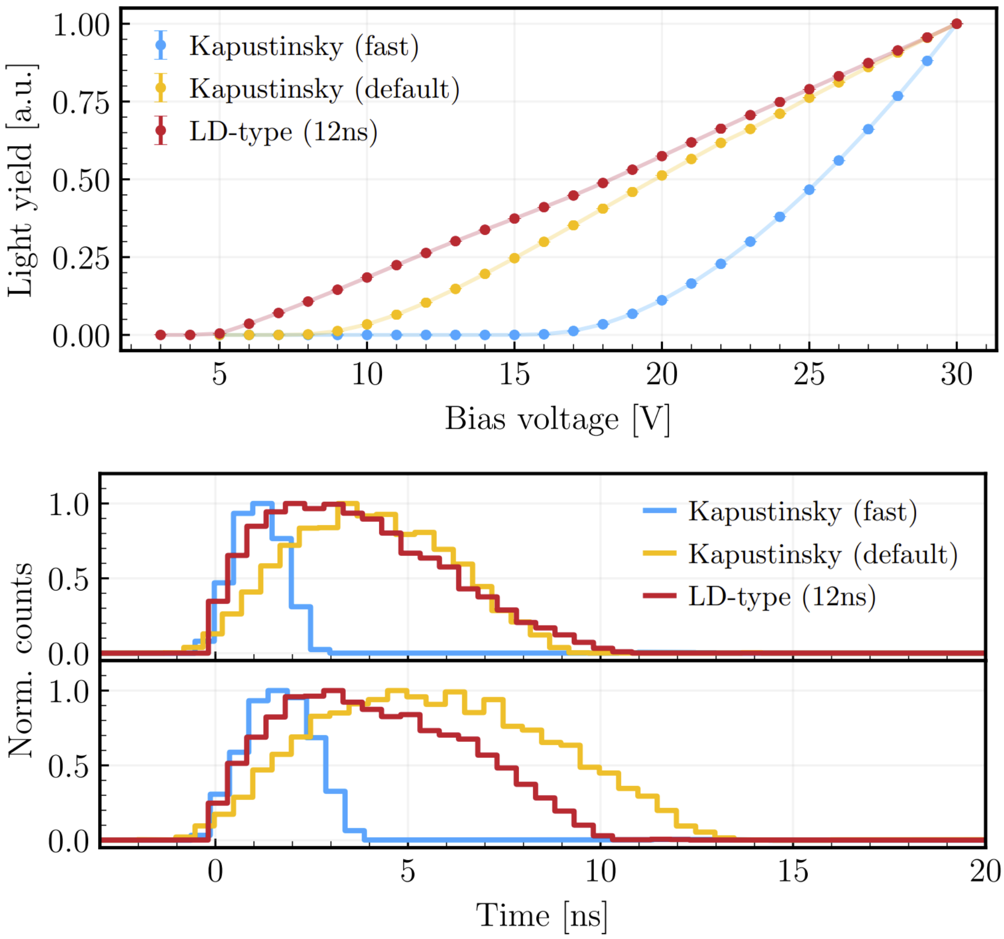

Figure 3. Intensity (top) and time profile (bottom) of the three pulse drivers used in the POCAM. Figures taken from [6].

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Lastly, the instrument design is completed with digital and interface electronics. The latter interfaces to the IceCube communication and synchronization protocol. Digital and distribution boards within the POCAM handle to distribute the signals to both hemispheres and control the device. The digital board furthermore takes care of the POCAM-internal DAQ, that is, self-monitoring and ambient sensors, current draws, voltages as well as temporary data storage and device configuration.

1.3 Calibration

In order to provide the instrument with traceable calibration several setups were developed. One of them is based on a two-axis rotation stage that allows scanning the emission profile of each POCAM flange to high precision. The second setup combines a temperature-regulated freezer with an optical calibration system that in turn is able to characterize relative intensity, time profile and spectrum of each of the POCAM pulse drivers. Both setups are pictured in figure 4 and preliminary measurements look promising.

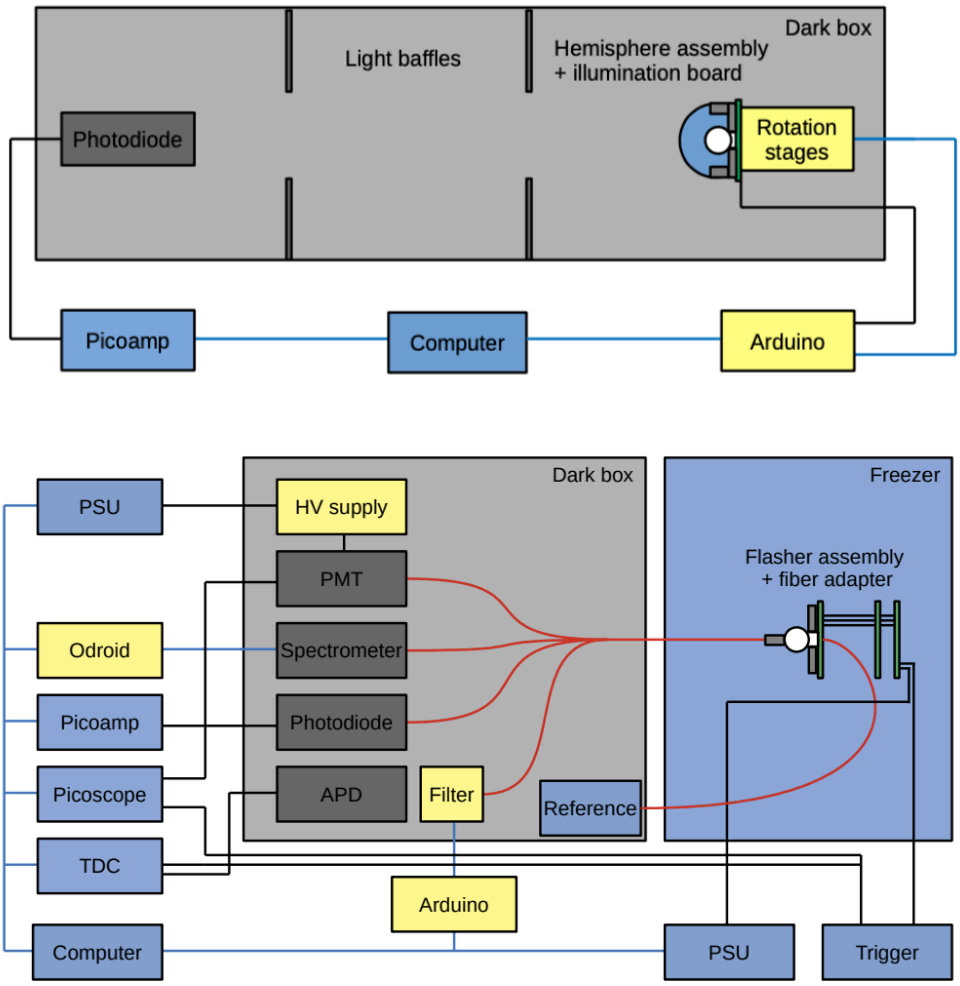

Figure 4. POCAM calibration setup schematics for emission profile scan (top) and flasher calibration (bottom). Figures taken from [6].

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1.4 Conclusion

The developed POCAM calibration light source aims to provide a reference for optical calibration in large-volume Cherenkov detectors. It encompasses self-monitored, nanosecond light pulsers and integrated self-monitoring sensors, all with traceable and absolute calibration properties with respect to ambient temperature and internal configurations. For a first application, this final POCAM iteration will be installed within the IceCube Upgrade next year.

Acknowledgments

We acknowledge the support by SFB1258 and the Cluster of Excellence. Additionally we thank the Baikal and STRAW collaborations for the deployments of the POCAM and sharing of related detector data.

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