PROCEEDINGS OF SCIENCE

Cryo-PoF: Cryogenic power over fiber for fundamental and applied physics at Milano-Bicocca

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The power over fiber (PoF) technology delivers electrical power by sending laser light through an optical fiber to a photovoltaic power converter, in order to power sensors or electrical devices. This solution offers several advantages: removal of noise induced by power lines, robustness in a hostile environment, spark free operation when electric fields are present and no interference with electromagnetic fields. This technology is at the basis of the Cryo-PoF project: an R&D funded by the Italian Insitute for Nuclear Research (INFN) in Milano-Bicocca (Italy). This project is inspired by the needs of the DUNE Vertical Drift detector, where the VUV light of liquid argon must be collected at the cathode, i.e. on a surface whose voltage exceeds 300 kV. We aim to develop a cryogenic system, which is solely based on optoelectronic devices and a single laser input line, to power both the Photon Detection devices and its electronic amplifier. We will presents the first results obtained during tests performed in Milano-Bicocca laboratory.

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1. Introduction

The Power over Fiber (PoF) technology transmits laser power over a non-conductive optical fiber to an Optical Power Converter (OPC) in order to power sensors or electrical devices [1]. This technology offers several advantages: removal of noise induced by standard power lines, robustness in a hostile environment, spark free operation when electric fields are present and no interference with electromagnetic fields. This technology is already employed at industrial level and several producers of PoF systems are available on the market, but no one guarantees it at cryogenic temperatures. R&D for the application of PoF at cryogenic temperature started at Fermilab (USA) in 2020, motivated by the needs of the DUNE Vertical Drift (VD) detector [2]. In fact the Photon Detection System of the DUNE VD module, will be operate on the high-voltage cathode surface, in a prohibitive condition for using the copper cable.
In this framework, the Cryo-PoF project aims to power both photosensors (SiPMs) and their cold electronics, using a single Power over Fiber line and to tune SiPMs voltage bias as a function of the laser power. In this paper we will describe the Cryo-PoF setup and the results obtained in the first year of the project, at Milano-Bicocca laboratory.

2. The Cryo-PoF setup

The Cryo-PoF setup is composed by a laser source that, by means an optical fiber, goes to the Optical Power Converter (OPC). It is directly mounted on an electronic board with the DC-DC boost converter and SiPM amplifier and it is able to power the photosensors (SiPM). The Cryo-PoF setup is schematised in Fig. 1

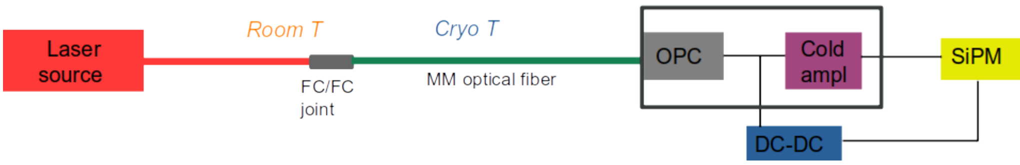

Figure 1: Schematic representation of the Cryo-PoF setup: the laser source is directly connected, through a FC/FC joint and a multimode (MM) optical fiber, to the OPC. The OPC, together with the DC-DC boost converter and the cold amplifier, is mounted on the electronic board, that powers the SiPMs and the amplifier. The laser source is at room temperature, while the electronic board is at cryogenic temperature.

The laser source is a 808 nm GaAs laser, manufactured by Broadcom company, that exits directly with a multimode optical fiber with a 62.5 μm core diameter [3]. The laser wavelength is selected to be as farther as possible from the SiPMs photon detection efficiency peak, that is around 500 nm [4]. This device permits to tune the output power by means of the applied input voltage, permitting the selection of the laser power.
We characterised the source at room temperature, in terms of linearity, power losses connecting an addition optical fiber and stability over time. We measured a ~ 4.5 % power loss adding a FC/FC joint and an additional optical fiber. This optical fiber is a graded index optical fiber, with a 62.5 μm core diameter and a black plastic sheath (to prevent any possible light leakage).
Registering the laser power for 2 hours with a fixed power $P_0 \sim 1$ W, we found a quite stable output over the time: P_{max} - $P_{min} \sim 5.7\%$ with an average difference of Mean($P_0 - P_i$) = 17.1 mW, where

P_i is the power registered at the i time. Since we notice a worse instability during the first 30 min of operation, we exclude this time from the calculation and we found: P_{max} - P_{min} ~ 0.96% and Mean($P_0 - P_i$) = 15.9 mW .
The key component of the PoF line is the Optical Power Converter (OPC), manufactured by Broadcom company [5]. This device transforms the laser light into voltage up to 7 V . We tested its performances evaluating the maximum power and current both at room and cryogenic temperatures (liquid nitrogen and liquid argon) for different power P_{in}. To evaluate them and to calculate the efficiency, we measured the IV curve by means of a Keithley 4200A-SCS semiconductor parameter analyser. The efficiency at room temperature is 50%, with a maximum current delivered of 91.4 mA, while at cryogenic temperatures, the efficiency lower at 30%, with an I_{max} = 82.4 mA.
The OPC is mounted in the electronic board and its output voltage powers the other components of the electronic board, i.e. the SiPM cold amplifier and the DC-DC boost converter, and the SiPM.
The DC-DC boost converter is developed by INFN Milano group and is boost the OPC output voltage to the desired SiPM bias [7]. The version we used in the tests needs V_{in} ~ 5 V, with a V_{out} between 40 V and 50 V, at liquid nitrogen temperature, to give bias to SiPM used in the test; as shown in Fig. 2, the DC-DC V_{out} can be set as a function of the laser power.
The cold amplifier is developed by the DUNE Milano Biccoca group [6]; it needs V_{in} = 3.3 V as input and it amplifies the SiPMs output signal.

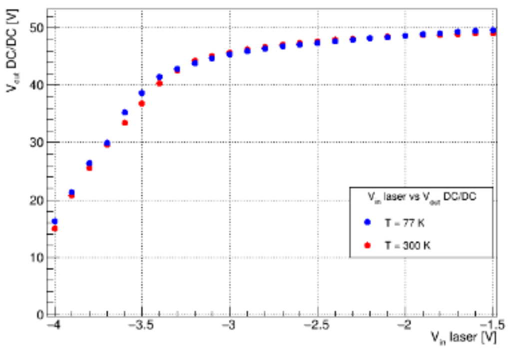

Figure 2: DC-DC V_{out} as a function of the input laser power: the laser power is proportional to the applied input voltage (V_{in}laser). The blue dots corresponds to test in liquid nitrogen, while the red one at room temperature.

3. Test at liquid nitrogen temperature

We tested the performances of the Cryo-PoF line powering 20 SiPM Hamamatsu in a liquid nitrogen bath (see Fig. 3). To reduce the DC-DC induced noise, it is screened by a metal box. The SiPM used for these tests are specifically developed by Hamamatsu for the DUNE experiment, with a breakdown voltage of V_{bd} = 42.0 V at cryogenic temperature [4].
SiPMs were illuminated by a LED light and biased at three different overvoltages (OV): 45 V, 46 V and 47 V. For each OV, 10k waveforms were registered. In order to evaluate the Cryo-PoF performances, we powered the system both with standard copper cables and with the Cryo-PoF system.

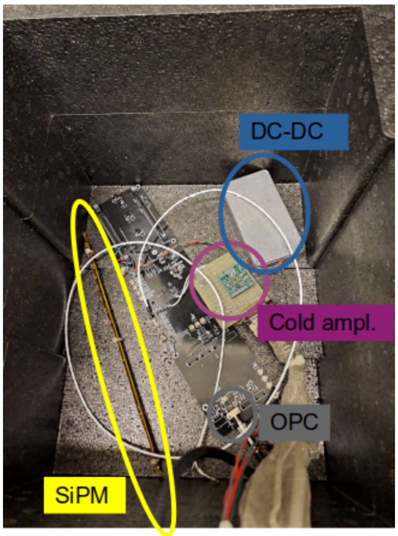

Figure 3: Picture of the Cryo-PoF electronic board: the OPC (gray), the amplifier (purple), the DC-DC box (blue) and the 20 SIPMs (yellow) are highlighted.

SiPM bias	SNR copper cable	SNR PoF
45 V	7.830	7.520
46 V	10.665	9.409
47 V	13.004	11.070

Table 1: Signal to Noise Ration (SNR) of 20 SiPMs Hamamatsu, biased with standard copper cable and the Cryo-PoF system, at three different overvoltages.

In Tab. 1 the Signal to Noise Ratio (SNR) obtained with the two configurations are shown: the performances of the PoF are comparable with the copper cable ones. Residual noise from DC-DC probably lowers Cryo-PoF performances.

4. Acknowledgment

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