PRIN 2020
“Photon detection in Extreme Environments for Fundamental and Applied Physics”
Aggiornamento attività UR Milano - Relazione Scientifica

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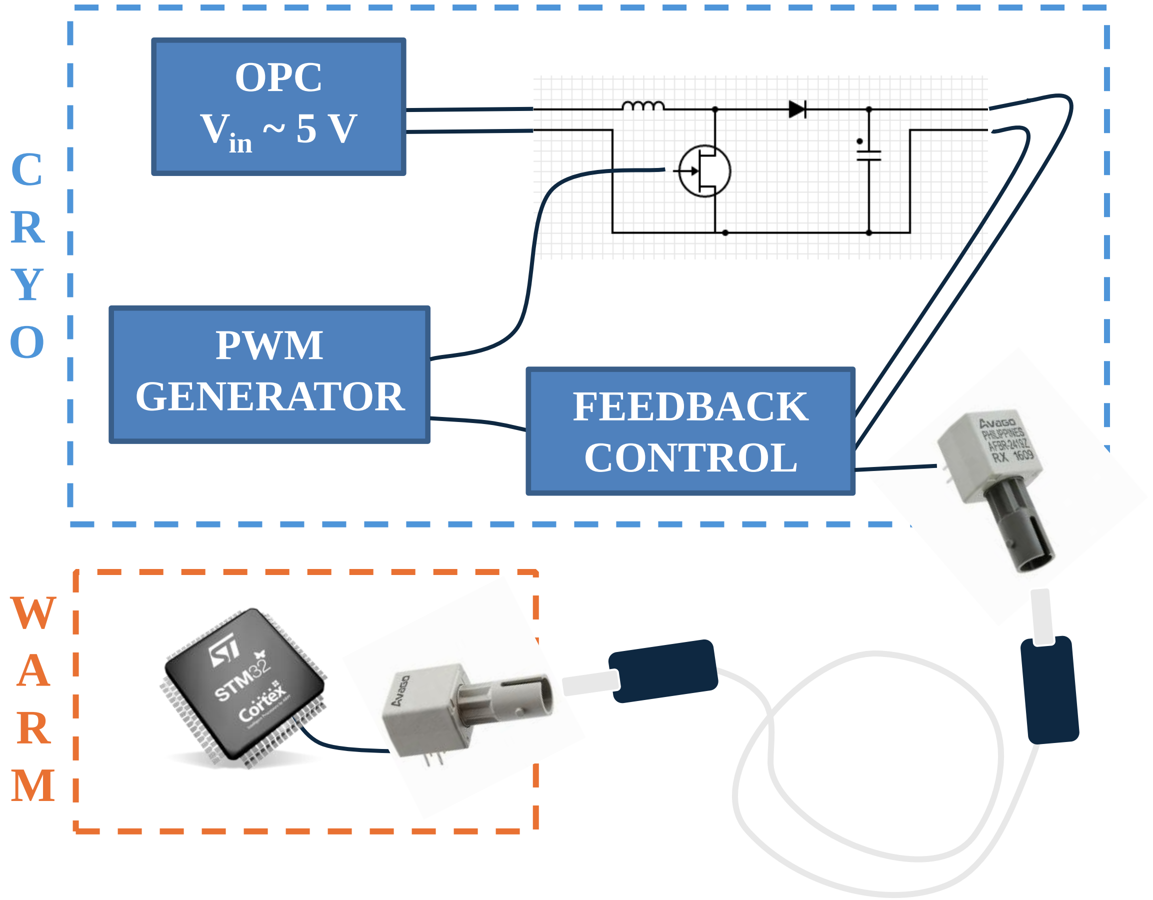
Outline

- **DC-DC Boost Converter**
  - System overview
  - Control design
  - Test results
- **Optical link**
  - Interference board
  - Preliminary test results
  - Laser box
- **Conclusion and future developments**

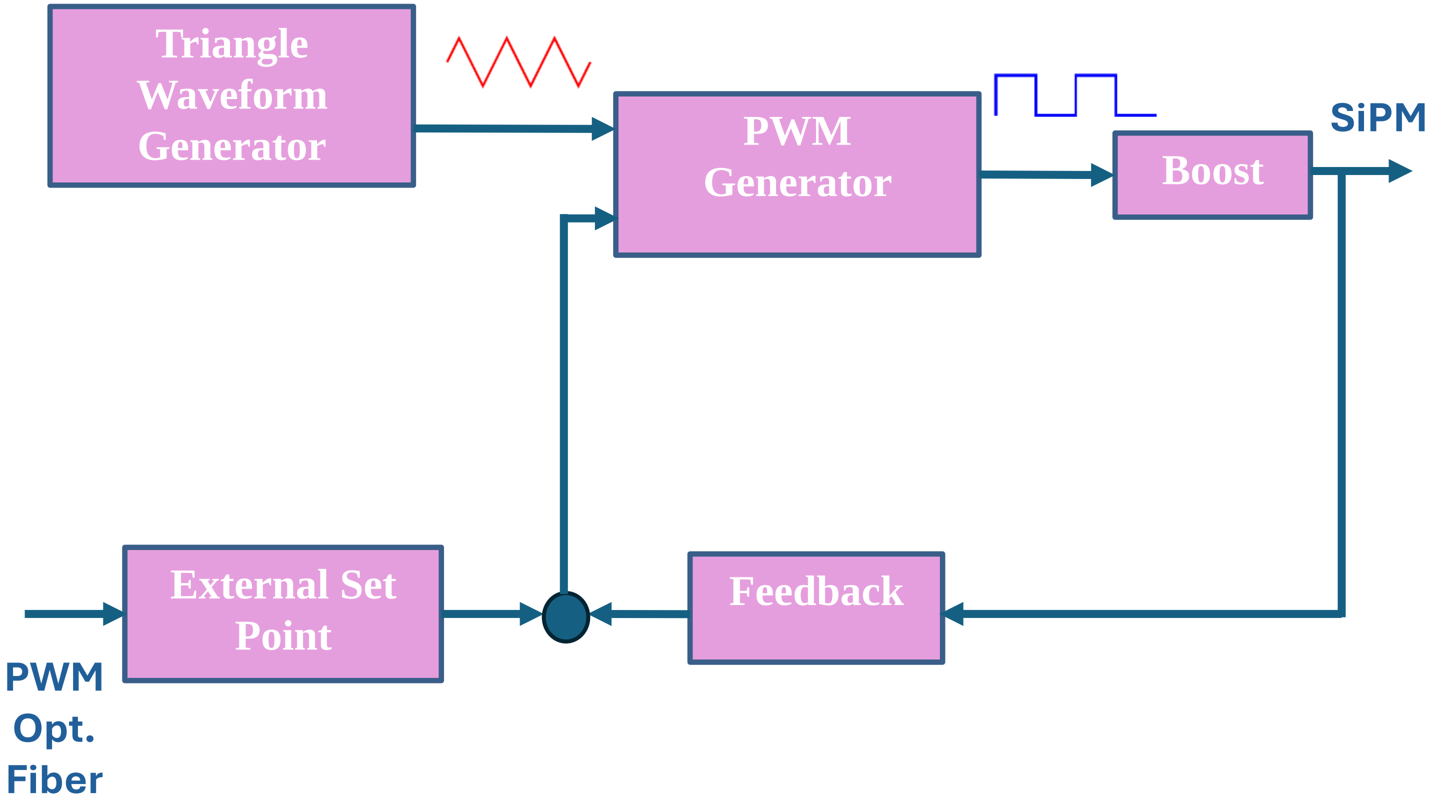
DC-DC Boost Converter – System overview

- Evolution in relation to the **DUNE Collaboration**
- **DC-DC Boost Converter**: high voltage to bias SiPMs at cryogenic temperature (77 K for LN_2)
- **Power supply provided by OPC** (Optical Power Converter): V_{in} = 5 V
- **Pulse Width Modulated (PWM) generation** with two possible controls:
  - ➢ Inner feedback setting output voltage at nominal point: V_{out} = 48 V
  - ➢ Optical input to change the setting voltage within few volts



DC-DC Boost Converter – Control design

- **Triangle-Waveform Generator:** it produces a triangle-like signal used for comparison, serving as a reference signal to control the Boost
- **PWM Generator:** it provides the MOSFET control signal, comparing an analog value with a triangle waveform
- **Boost Section:** responsible for storing the energy required to supply the SiPMs
- **Feedback:** it adjusts the analog level to counterbalance output variations and fix the operating point
- **External Set Point:** it can vary the output voltage using an external PWM



DC-DC Boost Converter – External control

NEW !

The DC-DC converter includes a **remote control** able to determinate different output voltages operating through a **connection at room temperature**, while power supply units remain unreachable inside the cryogenic set-up.

Internal feedback

Output voltage control at desired set point with two configuration:

- **Nominal:** set at design stage and fixed throughout the entire run (e.g. 48 V for Hamamatsu SiPMs)
- **External:** set point modified through external communication (nominal set point in case of failure or no external control)

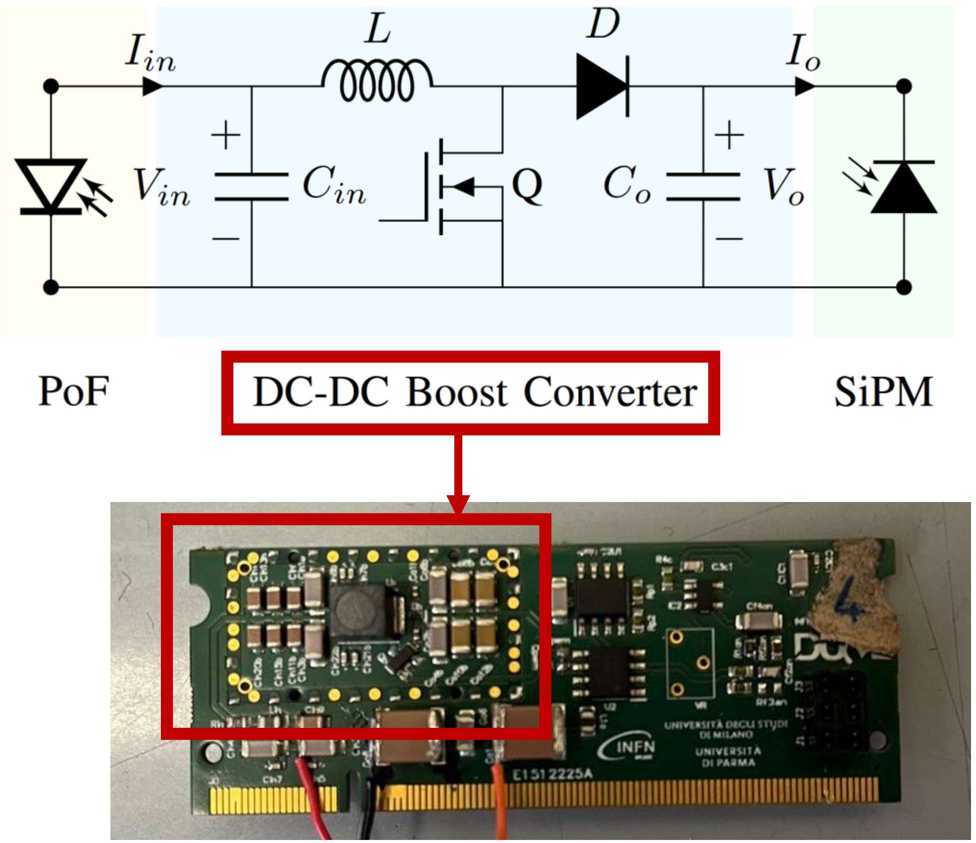
→

An external signal can be provided by an **optical fiber**, using an optical-to-electrical converter.

The design target is that of providing a 100 kHz PWM waveform and to be able to adjust the output voltage of a few volts.

DC-DC Boost Converter – Version 3

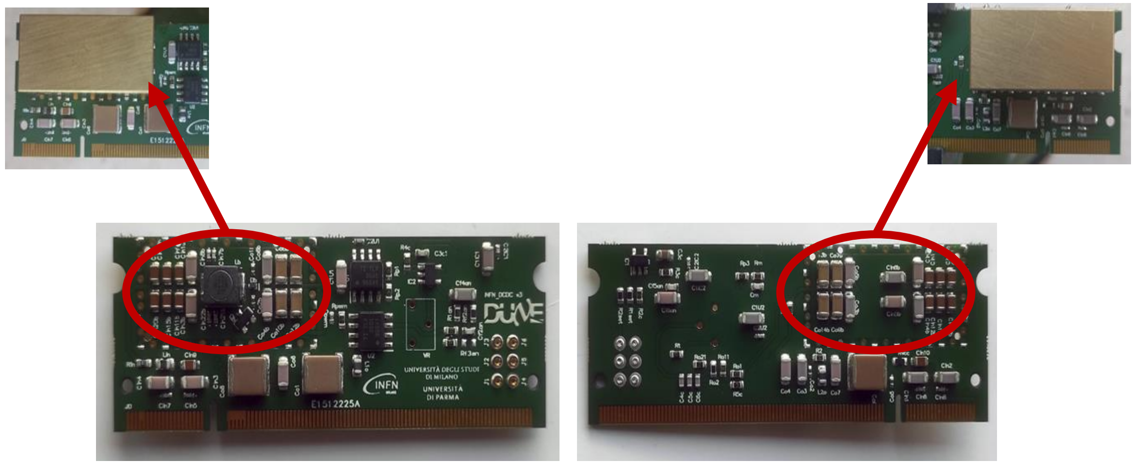
Schematic of the DC-DC Boost Converter (top) and picture of one the prototypes tested (bottom).



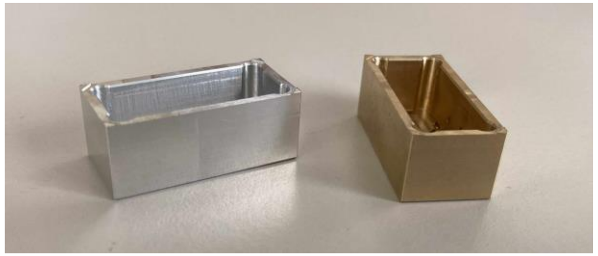
- **Discrete components** independently characterized at 77 K in the last two years
- **Working version** demonstrated in a test set-up at CERN
- Version 2 and Version 3 used in test set-up to bias SiPMs (Marta Torti presentation)

- Characterization of the **advanced DC-DC prototype (DC-DC v3)** with improved input and output filters, and optimized analog feedback control circuitry tested

DC-DC Boost Converter – Version 3



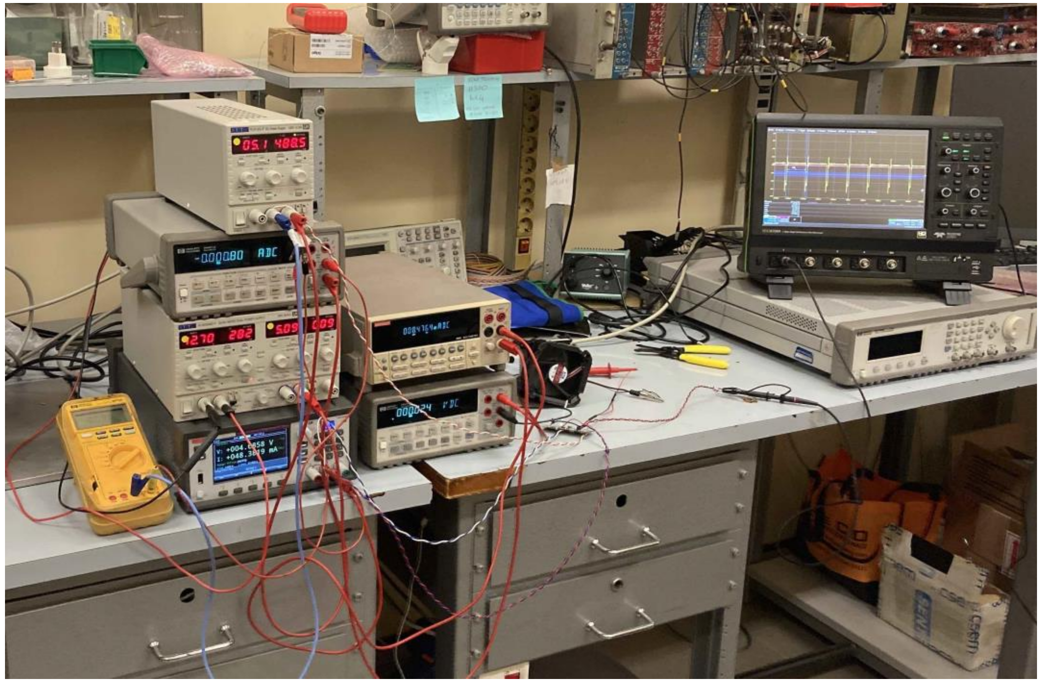
The board is designed with pads to solder an **Electromagnetic Interference (EMI) shield** for electromagnetic radiation, intended to be positioned over the boost.



Two types of shields were also produced by the Physics Department Mechanical Workshop, one made of **brass** (tested) and one made of **aluminum** (not optimal).

DC-DC Boost Converter – Test bench

Experimental set-up for the reconstruction of the DC-DC Converter **characteristic curve** and **efficiency curve**.



Room temperature

LN_2 temperature

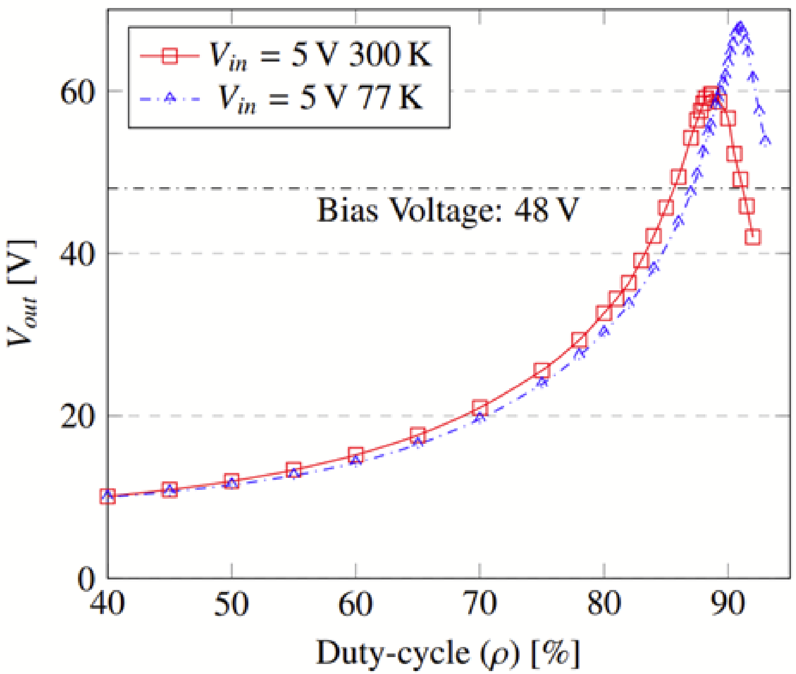
Experimental set-up for cryogenic measurements (77 K).

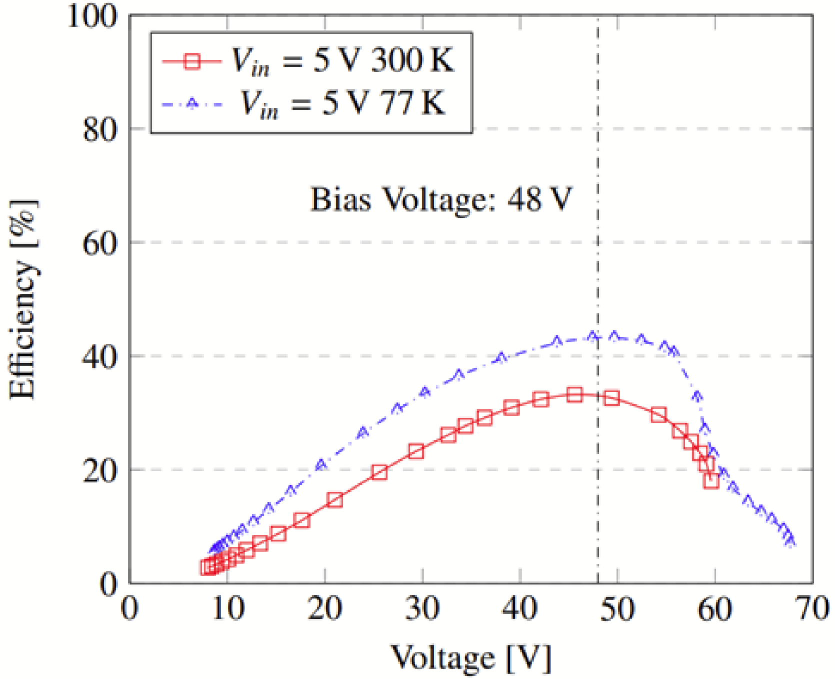
Inside the **dewar** there is the DC-DC board.

DC-DC Boost Converter – Test results

Measurements Results:

- T = 300 K: V_{out} is limited by the inductor series resistor
- T = 77 K: V_{out} = 68 V at 91% of duty-cycle
- T = 77 K at V_{out} = 48 V: efficiency is greater than 40%



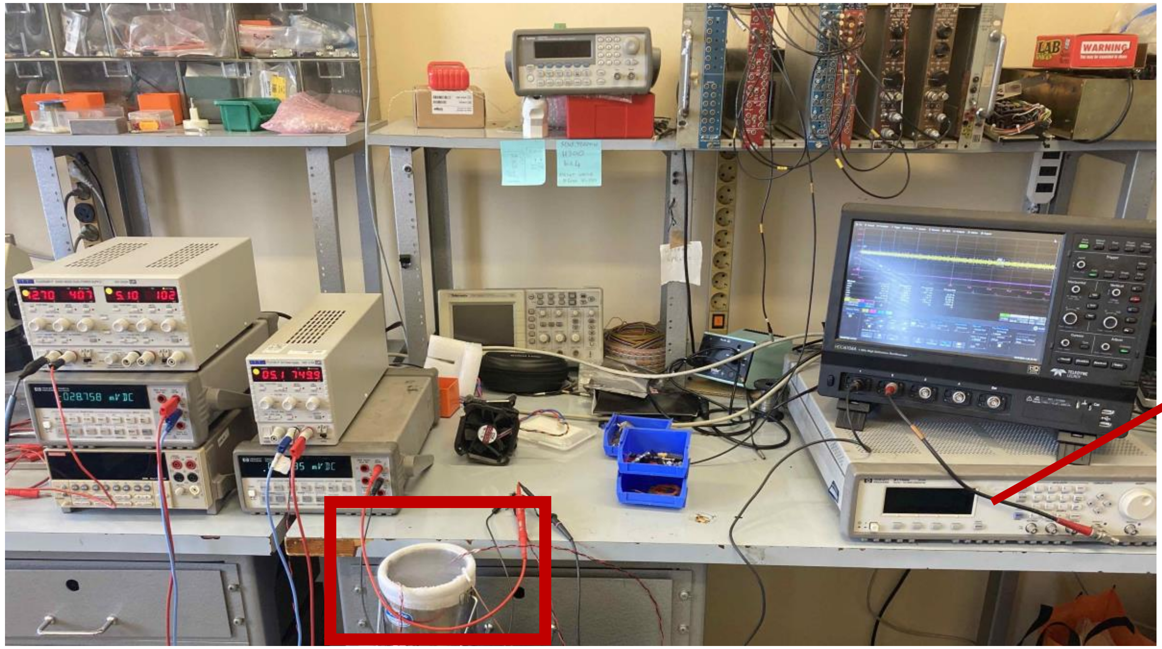


- ➢ Ascending at low duty-cycles: low current consumption
- ➢ Descending at high duty-cycles: high current consumption

DC-DC Boost Converter – Remote control tests

Experimental set-up for the study of the DC-DC Boost Converter **response to an external signal**.

Room temperature

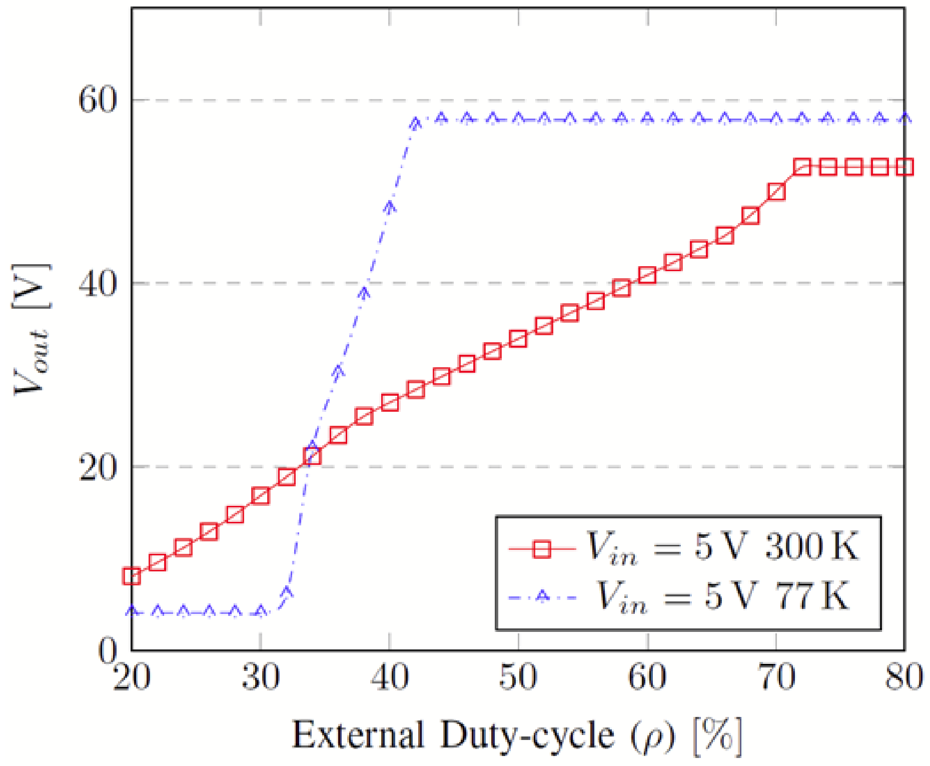


LN_2 temperature

Waveform generator for the external signal

DC-DC Boost Converter – Remote control results

- Configuration with nominal set point at 40 V: greater signal dynamics
- Tested with different resistor values: results with the optimal value (R_{1an} = 36 kΩ)



Test Results:

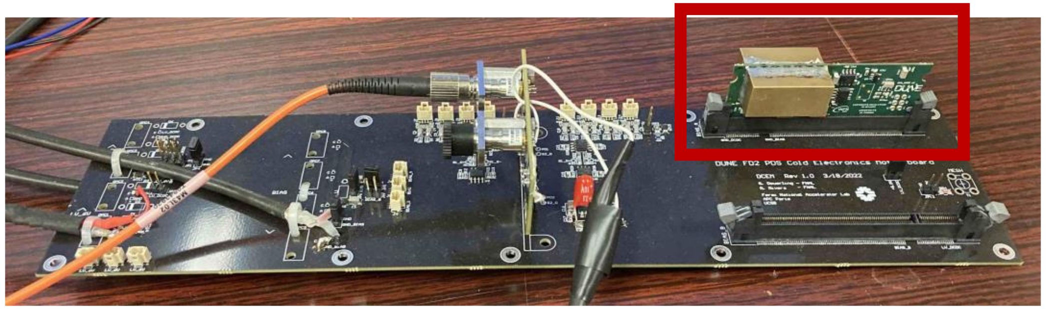
- **Linear trend** in the output voltage with the external duty-cycle
- **Steeper slope** at 77 K: saturation of the curve before 50% duty-cycle of the external signal

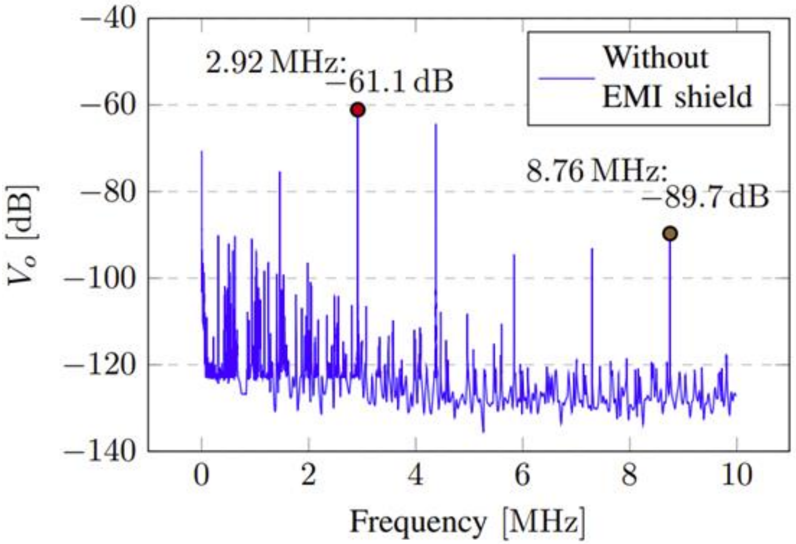
- Tests have to be further performed to investigate the performance

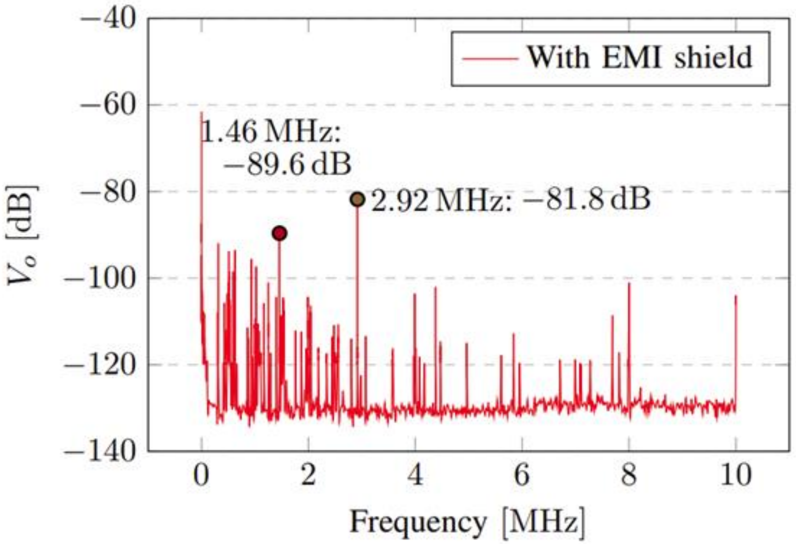
DC-DC Boost Converter – Noise results

Motherboard (from ProtoDUNE at CERN) with the DC-DC board mounted for the noise measurements.

Employing a Koheron optical-electric converter board, the **output signal from the DC-DC** converter was monitored.







Noise results in LN_2:

- Output voltage **FFT measurements** confirmed a **noise reduction** achieved with the EMI shield

Optical link – Operation and test

SiPMs in **a cryogenic and high voltage environment**: use of non-conductive cables.

Power over Fiber (PoF):

- To supply the DC-DC Boost Converter
- Crucial for the external boost control to vary the threshold of the output signal

New set-up for **investigating a fiber-optic system.**

Two key steps:

- Design and realization of an **interface board** between the optical fiber and the DC-DC Converter for the external control signal
- Design and implementation of a system for the **power supply and power regulation of the lasers** used to transmit the external control signal

Optical link – Interface board

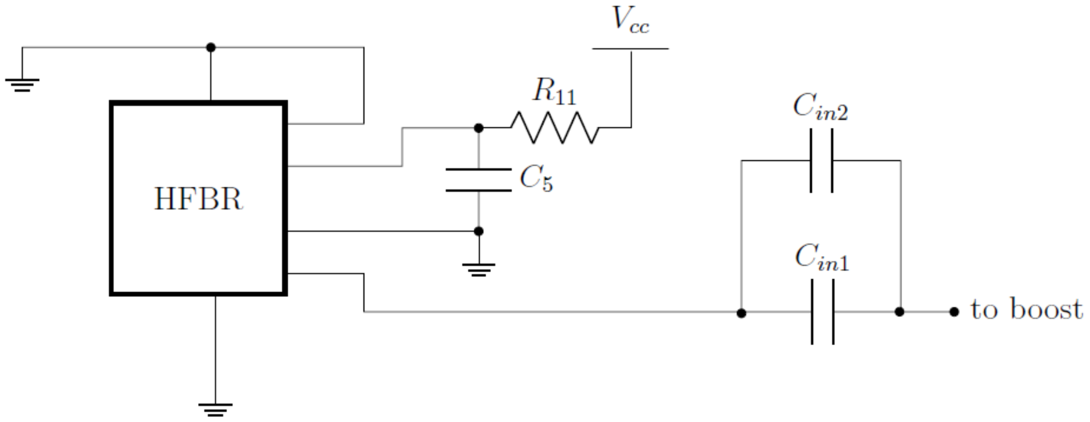
Various tests conducted to determine a suitable device for cryogenic temperatures:

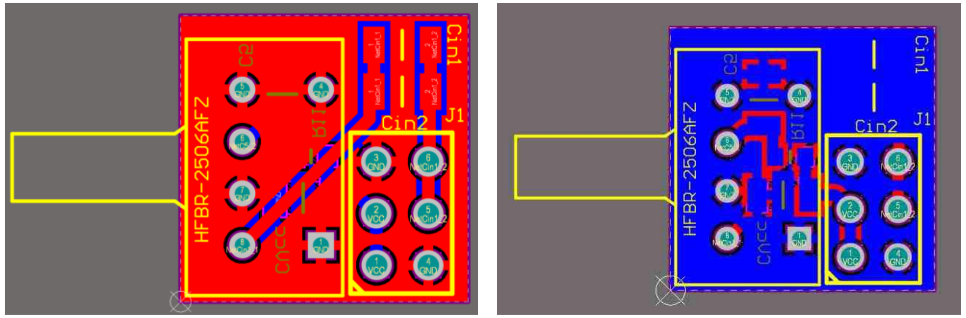
→ **Broadcom's HFBR-2506AFZ Receiver**

We need an **interface board:**

- Supply voltage V_{CC} to the receiver: **R-C filter**
- Two parallel capacitors (C_{in1} and C_{in2}): **filters for the output signal** from the receiver transmission to the DC-DC converter

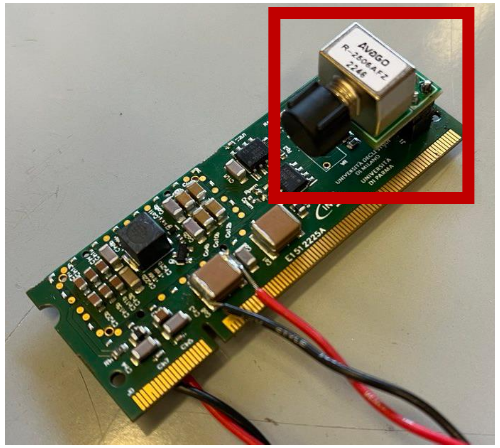
Schematic diagram and design of interface board.

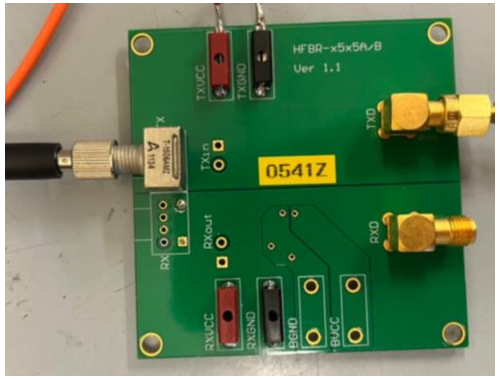




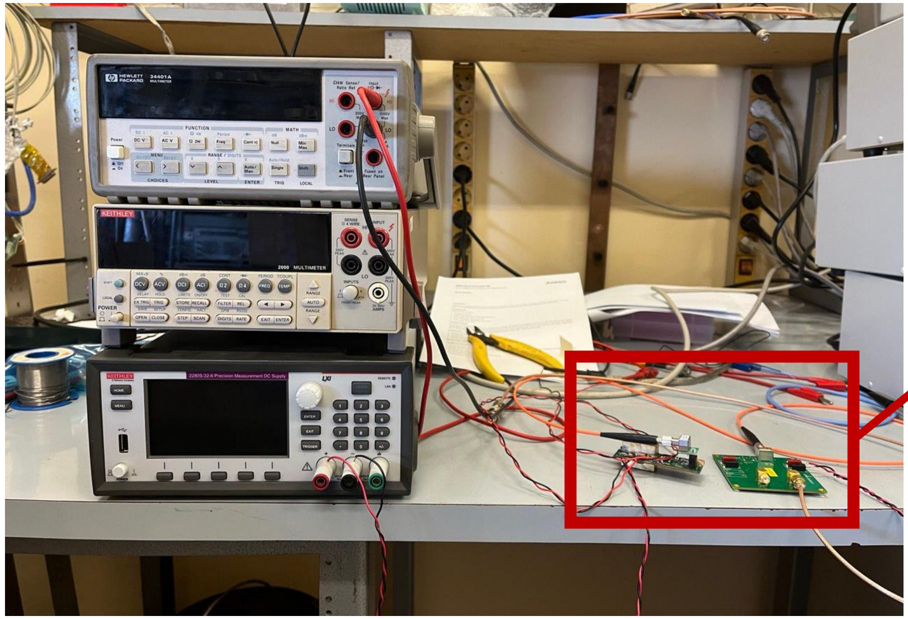
Developed by Andrea Riminucci during the Master's Thesis.

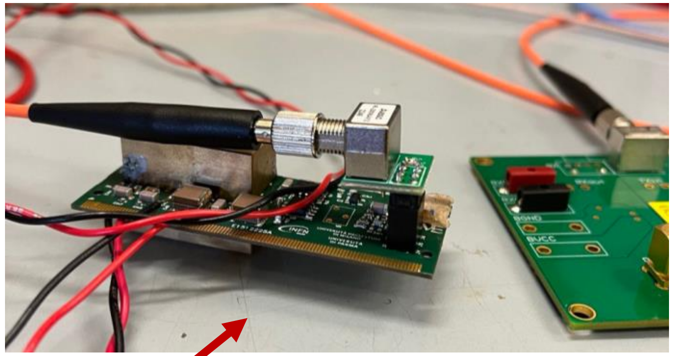
Optical link – Preliminary tests





Experimental set-up for the study of the DC-DC Boost Converter **response with optical link.**

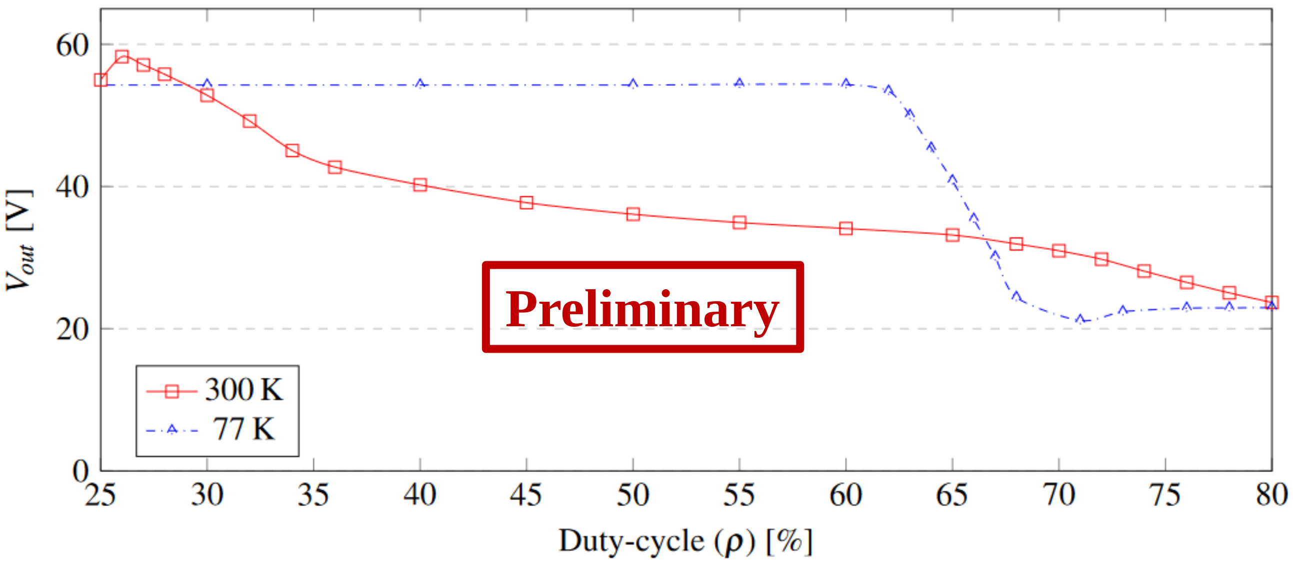




Interfaced board mounted on the DC-DC Converter. Preliminary tests performed at room temperature and 77 K.

Optical link – Preliminary results

- Configuration with nominal set point at 40 V: greater signal dynamics
- Tested with different resistor value: R_{1an} = 37.5 kΩ



Test Results:

- **Linear trend** in the output voltage with the external duty-cycle
- **Steeper slope** at 77 K: saturation of the curve before room temperature case
- **Limit** for output voltage at 77 K: V_{out} = 54 V

- Tests have to be further performed to investigate the performance

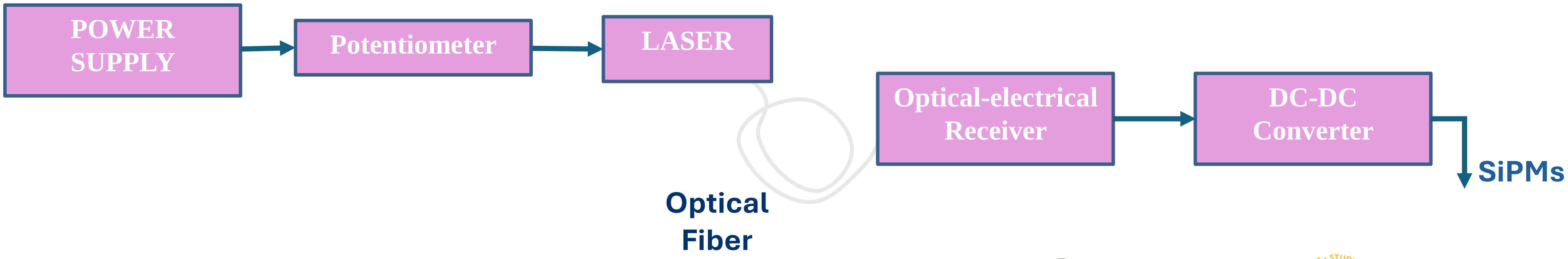
Optical link – Laser box design

System for the **power supply and power regulation** of the lasers used to transmit the external control signal.

Lasers:

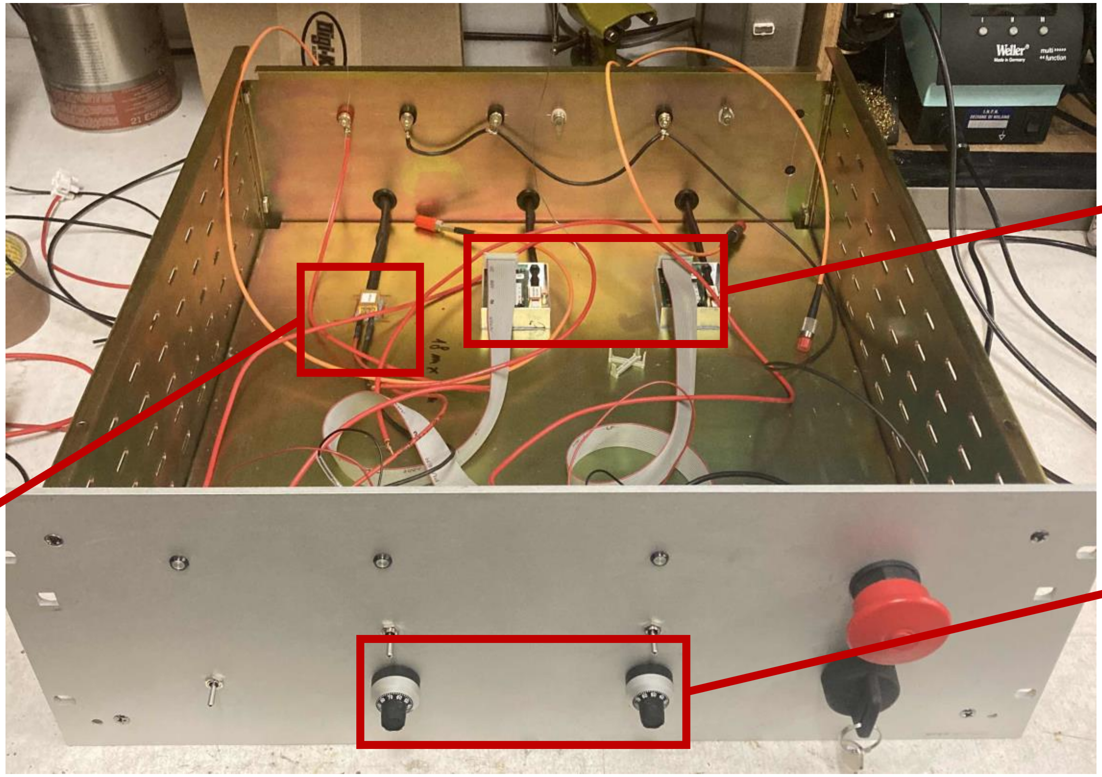
- Two Broadcom AFBR-POMEK2204: laser power by varying the supply voltage
- Lumics LU0808T080-EH05N12A 808 nm laser: directly controlled in terms of current

→ Shift the voltage control from the generator to **laser powers:** potentiometers for each laser to adjust the voltage at the laser input



Optical link – Laser box manufacturing

Picture of the laser box (work in progress)



AFBR - POMEK2204 (V_{CC} = 5 V)

Lumics LU0808T080 - EH05N12A (V_{CC} = 1.8 V)

Potentiometers

Conclusion and future developments

Results for the DC-DC Boost Converter version 3: → **More tests on the DC-DC Boost Converter version 3:**

Results for the DC-DC Boost Converter version 3:

- **Improved performance** at cryogenic temperature compared to room temperature
- **Noise reduction** achieved through the EMI shield
- Control studies provided an understanding of how the output varies in relation to the duty cycle of the **external signal**

More tests on the DC-DC Boost Converter version 3:

- More tests to **investigate the performances** of the circuit
- Input on the DC-DC Boost Converter via the **interface board**
- **Laser box:** multiple lasers with separate controls to supply power and introduce an external signal for control via optical fiber