Analog optical Signal Transmission for the VD-PDS

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Astroparticule et Cosmologie

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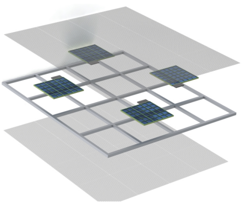
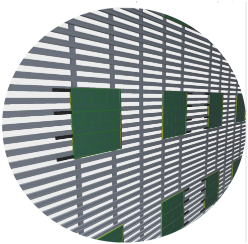
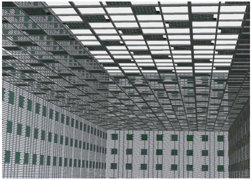
Introduction

- Many things have happened since the last Collaboration Meeting!
- Efforts have ramped up in our lab to provide the Vertical Drift concept with an option to read out the ARAPUCA SiPMs placed on a high voltage surface
- We decided to focus on an **analog optical transmitter**, motivated by:
  - similar pre-existing projects
  - low power consumption
  - fairly simple design (easier to find components that work well in LAr)





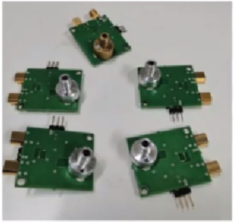


DarkSide readout system

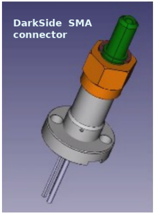
The DarkSide collaboration has developed analog optical signal readout for:

- the signal readout from their SiPMs
- readout of the veto system

- custom driver with cryogenic components
- LED @1310 nm with special lens
- custom SMA connector



Single channel prototypes



- Good performance in terms of linearity and stability, but
- does not meet DS radio-purity requirements yet
- Investigations on-going:
  - LED biasing and non-linear effects
  - choice of radio-pure materials (connector, epoxy, fibers)
  - improvement to minimize instabilities in LED-fiber coupling

Pictures taken from L. Rignanese's presentation

Requirement assumptions

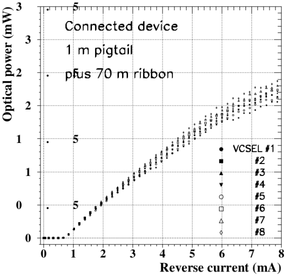
- Low power consumption
  - and limited power supply options $\rightarrow$ target 5V or 10V supply
- Single Photo Electron signal:
  - $\sim$ 20ns rise time $\rightarrow$ $\sim$ 50 MHz bandwidth target
  - few 100s ns fall time
  - 100 μV amplitude $\rightarrow$ total amplification needed is about 10
    $\rightarrow$ SNR$>$ 4
- Largest signal possible:
  - simulations show 2000PE as extreme event
  - target: achieve at least 1000PE
  - could be cut or covered with a non-linear transmitter
- Ganging of SiPMs provides a differential signal
  $\rightarrow$ recent news, to be incorporated into our design
- Ideally, the analog Tx would be placed next to the ARAPUCA tile $\rightarrow$ avoiding running copper cables accross cathode?

Optical Transmitter for DUNE - light source

- Different types of lasers have been studied at cryogenic temperatures
- Available literature shows lasers can work well in cold
- We started by testing VCSEL lasers of $\lambda \sim$850 nm
  - cheaper and easier to find
  - showed promising performance (in backup)
  - but are within the ARAPUCA sensitivity
- Finisar (now II-VI) Fabry-Perot 1310 nm laser diode
  Pigtail: SM 50cm fiber, terminated in FC connector

Two main concerns:

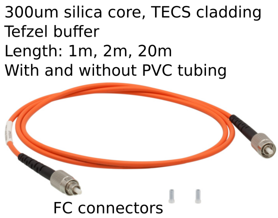
- tune of DC bias and power consumption
- coupled optical power at receiver end
  $\rightarrow$ coupling stability acknowledged as a key concern

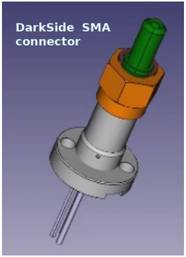


Optical Transmitter for DUNE - fiber connector

We are looking into different solutions:

- pigtailed laser with long SM fiber to feedthrough
  → in contact with provider
- pigtailed laser with short SM fiber connected to long MM fiber
  → will receive components before the end of the month
- laser in FC connector and long MM fiber
  → in contact with provider
- laser and in-house designed connector
  → on hold for now but discussed in the lab. Could be shared with digital?



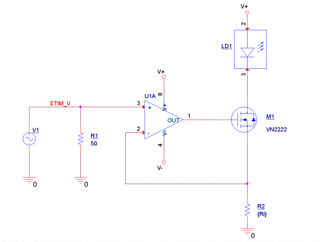


Laser driver

Design of a current driver for the laser diode:

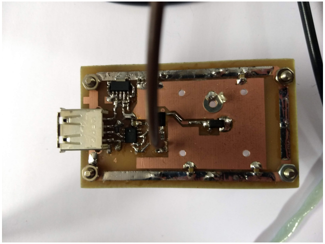
- selection of components based on
    - speed requirements
    - probability to work in LAr
    - power supply
- low noise to achieve S/N $>$ 4 for SPE
- good linearity over the expected range of ARAPUCA SiPMs signal

Initial design of basic current source



Simulations done to optimize components combination

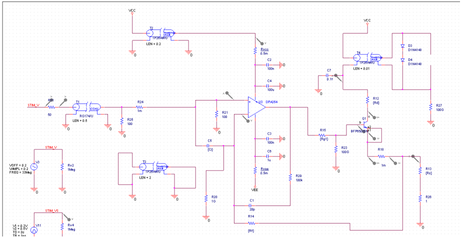
First set of test boards for high frequency and cryo tests

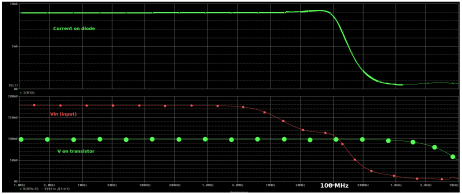


Laser driver design

Current best candidate simulated and implemented in home-made test board

- OPA354 CMOS opamp: 250 MHz BW, 2.5-7.5V supply, rail-to-rail, slew rate = 150 V/μs
- BFP650 SiGe transistor

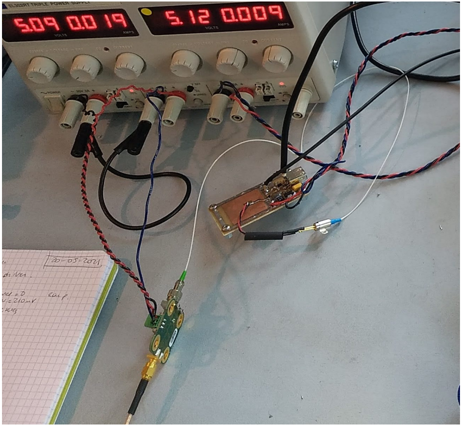




- Simulation shows good stability for small signals up to 100 MHz
- Now working to add SiPM ganging model and 1st stage amplification (thank you Gustavo for the files!)

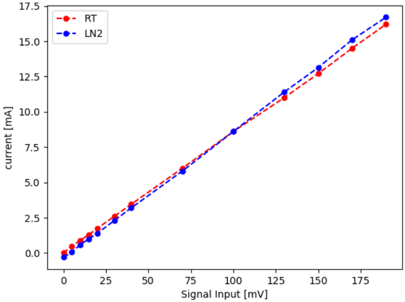
Laser driver testing

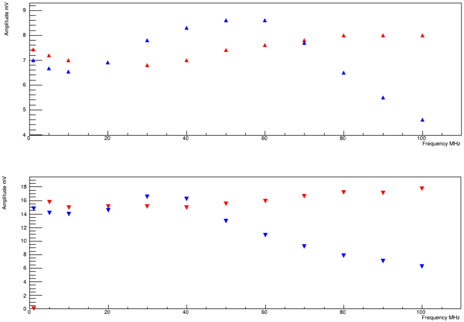
- Board implemented in home-made setup
  → performance expected to improve when professionally made
- Tests at RT and cold show good performance
- Multiple RT-cold and on-off cycles and ”mis-handling” shows components are sturdy



Laser driver test - no laser

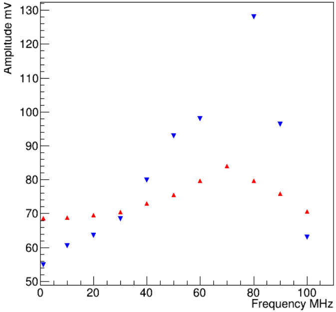
- Current output vs input voltage:
  $\rightarrow$ linear
  $\rightarrow$ identical behaviour in RT and LN_2
- Bandwidth measured for a sinusoidal signal of 100 mVpp and 200mVpp
  $\rightarrow > 100$ MHz at RT
  $\rightarrow$ reduced in LN_2 to 80/60 MHz but still acceptable

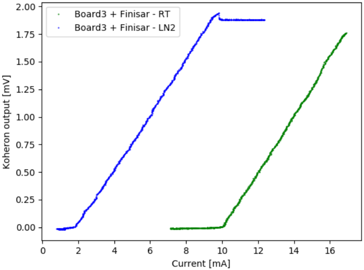




Laser driver/laser/receiver test

- FP-1310-5I-50SMF-FCAPC laser
- Koheron PD100 DC coupled receiver with InGaAs





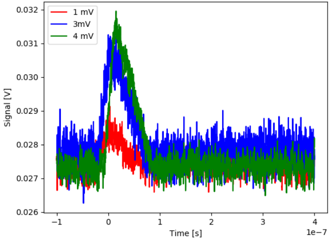
- Bandwidth measured for a 10 mVpp input signal at RT and in LN_2
- Lasing current of Finisar goes from $\sim$ 10mA in RT to $\sim$ 2mA in cold
- same slope is kept
- Reaches saturation point for receiver ($\sim$ 600μW)

Laser driver/laser/receiver test

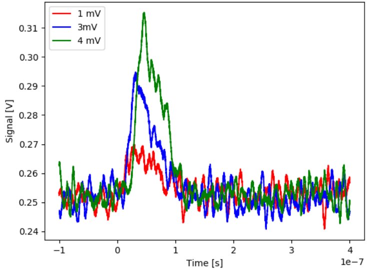
Test of ”small signal response:

- pulse t_r= 16ns , t_f= 58ns
- amplitude 1mVpp, 3mVpp, 4mVpp
- submerged in LN_2

Input signal (Function generator)



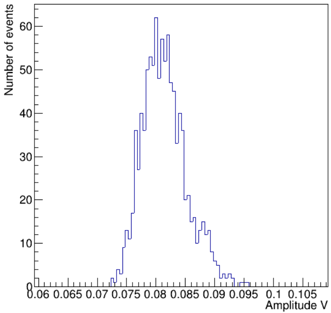
Signal out of receiver



Signals look very noisy but setup is not ideal

Laser driver/laser/receiver test

Histogram of signal values



- The whole circuit seems to have fairly low noise level on the output: 4mV RMS (in 800mV)
- Measured with a small input signal
- It should be possible to transmit a SiPM signal < 1 mV

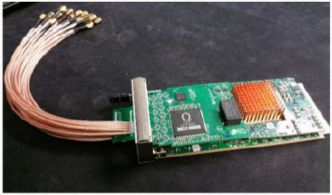
Receiver - outside cryostat

- Tests carried out with off-the-shelf receivers & oscilloscope:
  - FEMTO: PIN Photodiode with max sensitivity @ $\sim$ 800 nm, 200 MHz BW, 20 mV noise
  - Koheron PD100: InGaAs photodiode, 900-1700nm,110MHz,3mV noise

- To be followed up in-house SFP-like receiver:
  - low dark current PIN Photodiode
  - 450 MHz ultra low-noise TZ preamplifier

Digitization: either DAPHNE or readout developed for DualPhase

- μTCA standard
- commercial motherboard with a StratixIV FPGA
- Custom daughter board:
  - 14 bit ADC chosen (AD LTC2155-14)



Previous development for Dual Phase

Next steps:

- Fibers and FC connectors in LN_2:
  - measure loss due to FC-FC connectors
  - measure loss over 20m fiber
- Driver:
  - add 1st stage amplification
  - circuit design for next PCB is ready - production next week
  - test with SiPM board
- Integration: several questions still to be discussed
  - Input from xARAPUCA: signal range/rate
  - Feedthroughs
  - Fiber length needed
  - Physics goals?

Conclusions

- We have a prototype chain working with pulse generator input and oscilloscope readout
- Current laser candidate:
  - pigtail -FC connector - long fiber $\rightarrow$ need to verify loss
  - non-pigtailed $\rightarrow$ need custom connector (same as digital?)
- Diver candidate:
  - Achieved acceptable performance in terms of BW and small signal transmission
  - Need to add 1st stage amplification and DC offset
  - Evaluate dynamic range with SiPM input
- Receiver:
  - COTS option (Koheron) seems satisfactory but might have low saturation
  - in-house design is possible (easy)

Back Up

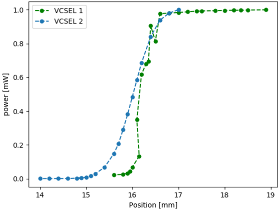
Optical Transmitter for DUNE - light source

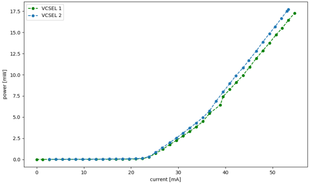
First tests done on a 850 nm VCSEL look promising, chosen based on colleagues advice and market availability:

Optical tests at warm:

→ beam characterization

→ factory consistency

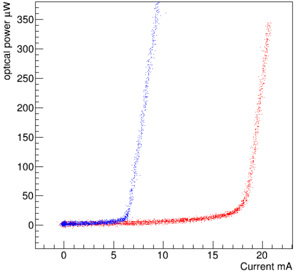




Tests in cold:

→ changes in properties

→ coupling possibilities



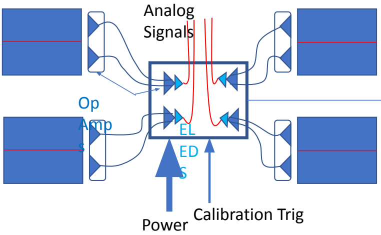
Coupled optical power output

→ Threshold current ∼7 mA

→ Reach 500 μW output at 10 mA

(with *modest* connection)

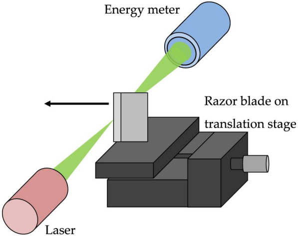
Electronics Box



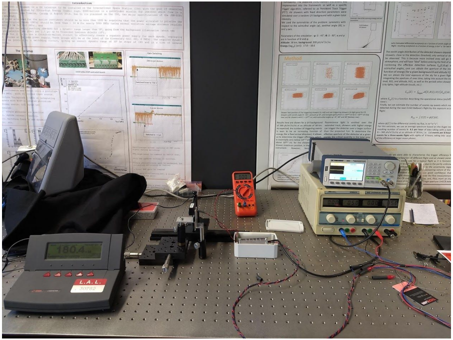
- Each Arapuca transmits two analog signals to the electronics box
- A summing amp combines both analog signals
- An analog transmitter, Tx (and conditioning electronics) transmits
- A calibration circuit (receives an ext. trig and plays a ramp into Tx)

This configuration will require 320 ELEDS/Cables Verses 640
Power for the op amps near the Arapuca will come from SiPM power
Power for Op amps on the electronic box will come from power voltage fanout

Optical tests at room temperature



Ophir Photonics PD300-UV:
1x1cm^2 10pW-300mW sensor



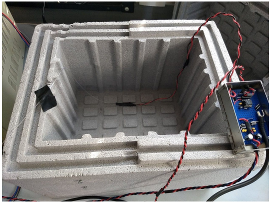
- Thorlabs 10mW VCSEL 850 nm - LP808010
- in-house current driver

Cold tests

- A first VCSEL 850 nm laser shows nice behaviour in cold: lower threshold and higher optical output. Will test second one tomorrow.
- A second 850 nm VCSEL that comes already with an ST connector shows no output in cold

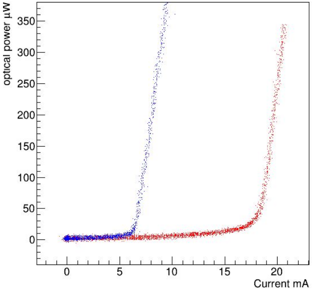
OPV314YAT: 850 nm, 1.4mW VCSEL with ST connector

No output in cold (or much higher threshold current)



Optical power measured by Femto Photoreceiver vs current:

- lower threshold
- larger power output
  (but diode saturates)



LED tests

- First setup to rehearse tests in cold
- LED (visible light) showed expected behaviour: larger light yield in cold
- Hand-made coupling was more stable than expected
  $\rightarrow$ motivation to test IR epoxy-case LEDs